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EGG BREAKING AND PROCESSING WASTE CONTROL AND TREATMENT

W. J. Jewell, et al

Cornell University

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Eleven percent of the eggs produced in the U.S. are handled by egg breaking facilities to produce more than 800 million pounds of various egg products annually. Five egg breaking plants were sampled which covered a size ranging from small installations to one of the largest. The wastewater was highly contaminated, with total COD exceeding 6000 mg/ℓ or greater. The product loss average was 12.5 percent of the weight of the processed product. Unit process losses were 0.034 kg BOD_5 and 7.5 liters per kg of egg liquid produced. In-plant waste conservation methods were demonstrated to decrease BOD_5 and wastewater volume losses by 50 and 24 percent, respectively. These reductions in product loss resulted in recovery of product with a value between $250 and $500 per day for a medium sized facility. Treatment of the wastewater by the activated sludge process and by aerated lagoons did not decrease the effluent pollutant concentrations to levels acceptable for direct discharge. Aerobic lagoons with 30 day HRT reduced the total COD from 5800 mg/ℓ to 1000 mg/ℓ. Of the four treatment systems tested, only a combination of an anaerobic lagoon followed in series with an aerated lagoon and a liquid solids separation step produced a dischargable effluent with soluble BOD_5 less than 15 mg/ℓ.

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ABSTRACT

Eleven percent of the eggs produced in the U.S. go to egg breaking plants to produce more than 800 million pounds of various liquid egg products annually. This study was conducted to determine the wastewater problems of this industry, the potential for reduction of wastewaters by in-plant management methods, and the treatability of the effluents. This report is divided into three sections - industry review, waste characterization and in-plant control, and treatability.

Five egg breaking plants were sampled which covered a size ranging from small installations (one egg breaking machine) to one of the largest (twelve breaking machines). Three facilities were extensively sampled before and after in-plant management methods were adopted to determine the effectiveness of source control of wastes. The waste generation characterization is presented on a unit production basis as well as absolute quantities and concentration. The effectiveness and difficulty of achieving various levels of in-plant waste control are documented.

Five conventional treatment systems were examined in the treatability study - aerobic lagoons, anaerobic lagoons, activated sludge, rotating biological contactors, and a system composed of an anaerobic lagoon followed by an aerobic lagoon. Basic engineering design information was developed for each process. Recommendations for use of various processes are made depending on the degree of treatment required.

This report was submitted in fulfillment of Project S-802174 by Cornell University, College of Agriculture and Life Sciences under the partial sponsorship of the Environmental Protection Agency. Work was completed as of August 28, 1974.

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SECTION I

SUMMARY AND CONCLUSIONS

Part I - A Brief History and Future of the Egg Breaking and Processing Industry

1. Economically, egg production is the most important facet of the entire poultry industry.

2. Eleven percent of eggs produced in the U.S. go to egg breaking plants resulting in 2.9×10^8 kg (6.40×10^8 lbs) of liquid egg products which grossed $195 million in 1969.

3. Egg breaking facilities are usually located close to egg production areas, are found in most states but are concentrated in the Southeast and California.

4. Except for the unusual growth rate resulting from World War II and government support effects, the egg breaking industry, as a whole, has grown at a linear rate of 1.3 percent per year. Although it is predicted that this growth will continue for the foreseeable future, there are some indications that trends may favor an increased rate of growth. Some large prepared food industries may construct egg breaking plants to increase efficiency, productivity, and market independence, Substitution of liquid egg products for other materials in such common products as ice cream also may increase the egg breaking capacity in the U.S.

5. Most egg breaking plants are located in small communities. The highly contaminated wastewaters generated in egg breaking industries can cause difficulties in municipal treatment facilities. In the five egg breaking plants sampled, the wastewater ranged between 8 percent and 1500 percent of the wastes generated from all other sources in the communities in which they were located.

6. It is estimated that more than half of the egg breaking facilities of the U.S., or about 100 separate plants are presently faced with waste treatment or disposal problems and will require assistance in the near future.

Part II - Characteristics of Egg Breaking and Processing Wastes Before and After In-Plant Waste Reduction

1. As in many industries, most of the plant managers did not know, nor did they have available methods to determine the amount of waste generated in egg breaking operations. They did realize that their overall losses might amount to 6 to 10 percent of the total output, depending, as they thought, on the egg shell strength.

2. Even though egg breaking plants process only 11 percent of the nation's eggs, and egg grading plants the remainder, losses from breaking plants exceed grading plant waste by more than ten fold, thereby presenting an equal or greater pollution potential.

3. Wastewater characterization indicated a highly contaminated discharge with COD's greater than 6000 mg/ℓ, and BOD_5 equal to about 60% of the COD. Although the nitrogen content exceeded requirements for aerobic biological treatment, the wastewater was phosphorus deficient. It was also slightly deficient in alkalinity required to support efficient nitrification.

4. Up to 15 percent of the total egg liquid output was lost to the sewer in plants where good in-plant management was not practiced. Losses equivalent to 3 eggs for every dozen broken were reported as maximum losses that occur in plants where no waste conservation measures were practiced. The average pre-modification product losses in all five plants sampled was 12.5 percent (by weight) of the processed output.

5. The measured average amount of liquid egg recovered per dozen eggs broken was 0.55 kg (1.21 lbs) and this represented recovery of 80 percent of the total egg weight.

6. The average egg liquid loss in a medium size facility (two or three breakers) represents a decrease in revenue between $500 and $700 per day.

7. The losses on a product basis averaged as follows: Before in-plant waste conservation 0.034 kg BOD_5/kg egg liquid produced and wastewater volumes of 7.5ℓ/kg (0.90 gal/lbs) egg liquid produced. In-plant modifications decreased average BOD_5 losses by 50 percent and decreased wastewater volume by 24 percent.

8. The simpler and inexpensive recommended in-plant controls were adopted by three plants. The egg washing water is a small volume and was eliminated from the waste stream in one case. Shell auger drippings and some other floor losses were relatively easy to control. However, pipe and pasteurizer flushings were not recovered.

9. In-plant waste control was found to reduce the waste generated from an average of 12.5 percent product loss to 6.4 percent product loss. This is equivalent to additional egg product recovered worth between $250 and $500 per day in a medium sized breaking facility, not including the savings from reduction in cost of waste treatment.

10. Adoption of in-plant waste control measures that cost less than $300 per plant could result in reduction of waste load equivalent to about two-thirds of that which is technically achievable. Good plant management appears to be capable of reduction of product loss to about 5 percent of the liquid egg output. If more extensive and costly modifications are made to the plant to recover the first flushing from pasteurizers, pipes, and tanks, the product loss to the sewer could probably be reduced to less than 2 percent of the output.

11. On a national basis in-plant waste control would result in annual product recovery of 3.2×10^7 kg (7×10^7 lbs) of liquid egg of a quality suitable for animal food which is now lost to the sewer.

12. The effectiveness of in-plant reduction of waste is not dependent on the size of the egg breaking operation. The portion of the product lost in small plants and very large plants was comparable, and dependent on the degree of management exercised.

13. The total solids concentration was found to correlate well with other major pollution parameters such as BOD_5. This may be a simple management tool useful for approximating waste loadings with this wastewater.

14. A qualitative relationship exists between the apparent color (not related to Standard Methods definition) and BOD_5 levels of egg processing wastewater and can be used to estimate egg liquid losses.

Part III - Egg Breaking Industrial Wastewater Treatability Studies

1. Egg breaking wastes as obtained from three facilities, A, B, and C, were highly biodegradable with no observed toxic effect to biological treatment processes.

2. High concentrations of organic material were not reduced to levels acceptable for direct discharge to surface waters in conventional processes, such as activated sludge and aerobic lagoons; even at low design loadings.

3. Aerobic lagoons, with hydraulic retention times (HRT) of 30 days reduced the total COD from 5800 mg/ℓ to 1000 mg/ℓ, and resulted in a high effluent turbidity.

4. Substrate removal coefficients in aerobic lagoons at 20°C ranged from 0.58 to 0.76 day^{-1}.

5. The longest sludge retention time (SRT) of 10 days tested with the activated sludge process resulted in an effluent quality as follows: total COD of 1140 mg/ℓ, total SS of 500 mg/ℓ, and turbidity equal to 100 JTU.

6. The activated sludge process had nitrification efficiencies of 5 to 70 percent, and the efficiency in the anaerobic-aerobic lagoon system

varied from 68 to 95 percent conversion.

7. The rotating biological contactor produced an effluent total COD of 320 mg/ℓ at loading rates less than 3 lb COD per 1000 ft^2 per day thus indicating that this process may require large capital costs for treatment of these wastewaters.

8. Anaerobic lagoons operated at HRT's varying from 5 to 20 days produced soluble COD removal efficiencies ranging from 64 to 92 percent at 20°C with a small decrease in efficiency at 10°C.

9. The substrate removal coefficient for anaerobic lagoons operated at 20°C was 0.63 day^{-1}.

10. When anaerobic lagoons were followed by 6 day HRT aerobic lagoons, the overall system efficiency COD removal was greater than 98 percent, at 20°C and 10°C, and at anaerobic lagoon HRT's of 5, 10, and 20 days. Effluent quality from the aerobic lagoon in a series system operating at 20°C with a 20 day HRT anaerobic primary unit averaged as follows: 90 mg/ℓ soluble COD, 13 mg/ℓ soluble BOD_5, 92 mg/ℓ NO_3-N, 21 mg/ℓ NH_3-N, and turbidity of 5 JTU.

11. Suspended solids (SS) accumulated in the anaerobic lagoon at the rate of 4 percent of the SS input at an HRT of 20 days and a temperature of 20°C in an unit that was not mixed before additions of the daily feed.

12. The effluent from the aerated lagoon following the anaerobic lagoon contained well flocculated SS which settled at a high rate, leaving a clarified effluent with a turbidity less than 10 JTU.

13. The daily accumulated sludge volume settled out of the effluent from the aerobic lagoon in the series treatment system was equivalent to about 2 percent of the treated volume.

14. A treatment system composed of an anaerobic lagoon followed by an aerobic lagoon with sludge recycle to the anaerobic lagoon will result in a low sludge disposal volume.

15. Design capacity should be related to maximum production capacity that can be achieved when eggs are plentiful during the months of May and June. In most facilities wastewater flows are very low at night and during weekends.

16. Of the units tested, the combination of an anaerobic lagoon followed by an aerobic lagoon with a clarifier offers the best potential to produce an effluent quality acceptable for direct discharge.

17. The activated sludge process, aerobic lagoon alone, anaerobic lagoons alone, or rotating biological contactors were all found to be suitable to produce an effluent that would be acceptable for discharge to a municipal waste treatment facility.

18. Odor generation was minimized due to formation of a half inch or deeper scum layer on the anaerobic lagoon. Although this layer was always effective in laboratory studies it may not be as effective in full scale units.

19. Aerated lagoons may require addition of inorganic carbon to support nitrification.

20. Although the wastewater appeared to be slightly phosphorus deficient for treatment in higher yield aerobic systems, this factor did not appear to limit process efficiency in activated sludge.

SECTION II
RECOMMENDATIONS

1. Information on the economic impact of egg losses and their relation to in-plant management techniques should be communicated to egg breaking plant owners and managers.

2. The feasibility of product recovery from egg washing solutions should be determined.

3. More extensive studies should be undertaken to evaluate the merits of egg washing in reducing bacterial count.

4. As a temporary solution, egg washing wastewaters should be segregated and trucked to land disposal sites.

5. The economics and feasibility of recovering the initial cleaning flushings from pasteurizers, pipes, and product holding tank should be investigated.

6. Egg breaking plant employees should be trained to recognize the advantages of recovering human inedible product for use as animal food.

7. A system of liquid level indicating probes should be connected to product pumps or alarms in order to avoid negligent spillovers from batch processing tanks in egg breaking plants.

8. The plant's wastewater effluent should be monitored and the results communicated to the plant personnel as a training aid to emphasize in-plant management as a waste conservation approach.

9. The promising results of the anaerobic-aerobic lagoon system obtained in this study indicate that the process should be considered for full scale application.

10. Further research needs to be conducted to determine the reasons for the significant difference between effluent quality produced by the series anaerobic-aerobic lagoon treatment and other conventional processes such as activated sludge.

11. Additional studies should be conducted to determine whether recycle of sludge in the anaerobic-aerobic lagoon treatment system can effectively control the waste sludge for an extended period of time.

12. Development of solid-liquid separation processes need to be undertaken in conjuction with further consideration of aerated lagoons or activated sludge processes for the treatment of egg breaking wastewaters.

13. Due to the low loading rate (3 lb COD per 1000 ft^2) necessary for successful operation of the rotating biological contactor, the economics of use of this treatment scheme should be further examined to determine its feasibility as a pretreatment process.

SECTION III

INTRODUCTION

This study of the egg breaking industry is divided into three sections: a review of the characteristics of the industry as a whole, characterization and control of wastes in five egg breaking plants, and investigations into the treatability of wastewaters from egg breaking facilities. The data are applicable to a wide range of plant capacities since detailed industry analyses included the largest and most complex egg breaking facility even though the majority of information was developed for facilities with one, two or three egg breaking machines. Although the waste problems associated with processing eggs to bring them to the shell egg market were not included, the first steps in shell egg handling are similar to those used in egg breaking plants. Therefore, portions of the data developed in this study could be used to approximate the waste problems of this division of the egg processing industry. The solid waste problems generated by egg breaking facilities were defined but the disposal alternatives were not developed in this study.

SECTION IV

OBJECTIVES

Egg processing industries represent a small portion of the total industries of the U.S. However, because they are often located in small rural communities and because their wastewaters are highly contaminated they can create significant water quality degradation. It was the general goal of this study to provide an overview of the industry which would include practical and inexpensive in-plant waste management methods and determine the problems of treatment of the wastes. The specific objectives of this study were to:

1. Describe the characteristics of the industry; past, present and future.
2. Characterize the wastewaters generated in specific egg breaking facilities representing small, medium and large production capacities.
3. Develop in-plant waste management techniques to minimize the generation of waste material.
4. Conduct treatability tests of actual egg breaking wastewaters to determine the feasibility of reduction of pollutants.
5. Use the treatability results to suggest least cost and low energy consuming processes for treatment of wastewaters to various levels of contamination.

The information in the following sections support the above objectives. It will be shown that this industry is growing steadily and that the combination of good effective plant management and use of simple waste treatment processes can achieve greater than 99 percent pollution control at a low cost to the industry. In situations where good in-plant management is instituted as a major part of the pollution control program, the decrease in loss of product may have the capability of yielding a return greater than treatment costs.

The egg industry includes both the shell egg and egg products industries, and as is true with most businesses, has developed an esoteric language peculiar to its trade. Whenever possible jargon has been eliminated, but a list of terms used in the egg industry is included in the Glossary.

SECTION I

IMPORTANCE OF THE EGG ENTERPRISE

The egg industry is, financially, the most important of the various poultry enterprises. In 1973, the egg, broiler, and turkey enterprises showed a gross national income of about $6.5 billion and eggs alone accounted for nearly half this total (1).

Within the State of New York the egg enterprise is even more significant since of the $75 million cash receipts received for poultry and poultry products in 1972, 81% was derived from eggs (2). Eggs and "greenhouse and nursery products" were tied for third in rank in comparison of cash receipts for all farm marketed commodities.

In the continental United States in 1973 there were 291,827,000 laying hens which produced 5,544 million dozens of shell eggs or about 6,700 million pounds of egg products. New York State ranked 12th in the number of layers with 8,916,000 and 13th in number of shell eggs produced (2,052,000,000) in the nation (1).

Of the total eggs produced in the U.S. in 1972, 11% of the shell eggs produced were broken for use in producing egg products (liquid, frozen and dried eggs) and the remaining 89% were sold in shell form (3). The value of liquid eggs produced in the U.S. in 1969 was $195,200,000 (4).

SECTION II

LOCATION AND REGIONAL CHANGES IN THE EGG INDUSTRY

SHELL EGGS

Although Figure 1 shows the location of chickens on hand three months old and over in 1969, it is an indication of the location of egg farms since the average trucking distance for most eggs is short. The location of egg farms in 1973 would be about the same as in 1969 excepting that there would be fewer and larger farms. The highest concentration of egg production is in the Southeast and California, but the industry is fairly uniformly distributed throughout the rest of the U.S. except for little activity in the arid western states. About 40% of the egg production in mainland United States is in the southern regions.

Over the last 15 years the percentage of total eggs produced in the South Atlantic region of the U.S. has increased from 12 to 21 percent of the total. Most regions have remained about the same with six of the seven major regions of the U.S. producing greater than 14 percent of the total (6). The period between 1969 and 1971 was stable indicating little shift between regions in the production of eggs (6). Although regional shifts will continue to occur over the next few years, it may be concluded that these changes will be more evolutionary rather than revolutionary.

Size of Flock

Small egg laying flocks have been disappearing in large numbers. In the United States the number of farms reporting chickens on hand (3 or 4 months old and over) decreased from about 1.2 million in 1964 to around 471,000 in 1969. The trends are summarized in Figure 2.

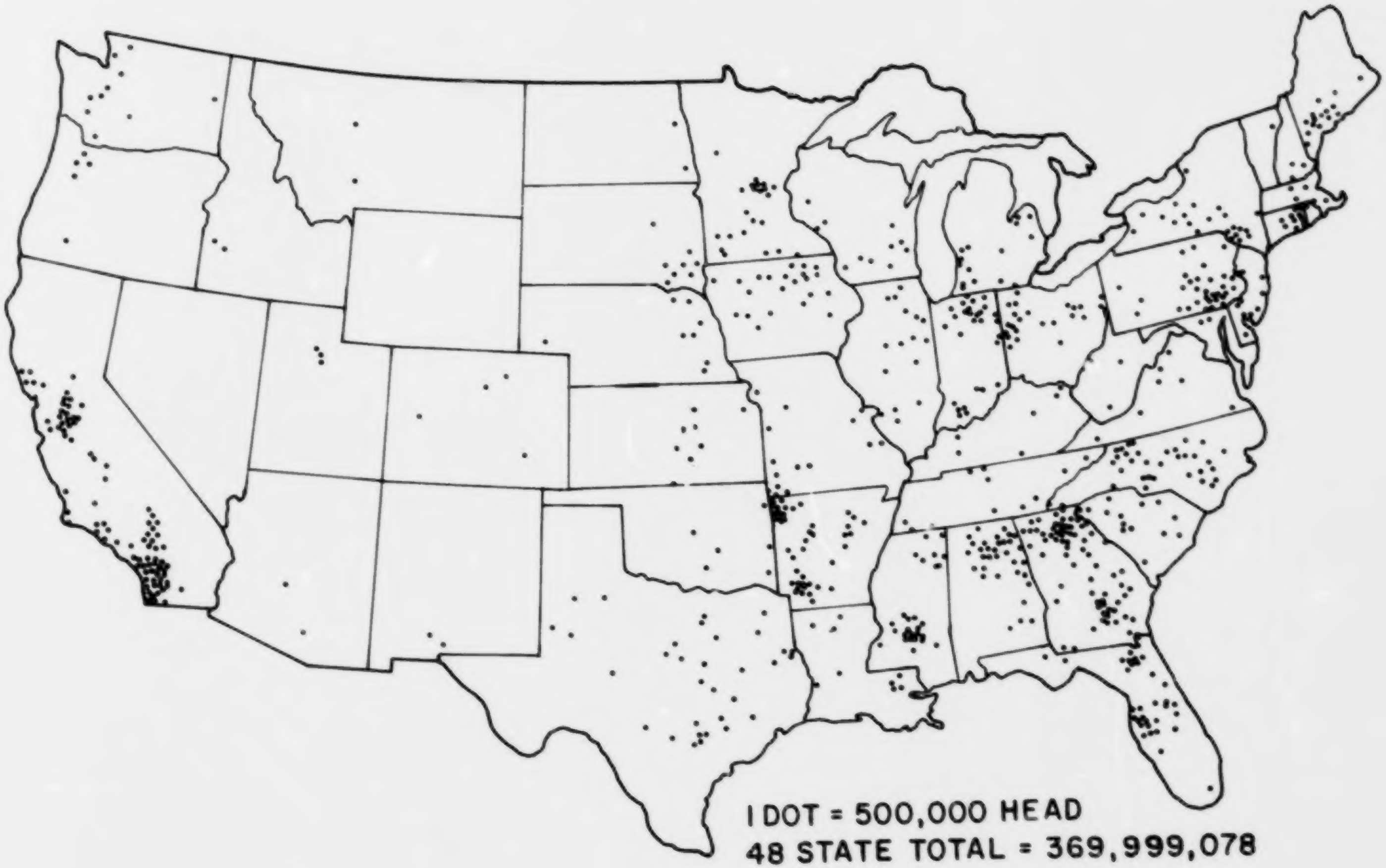


FIGURE 1. Distribution of chickens three months old and over in the U.S. in 1969 (5).

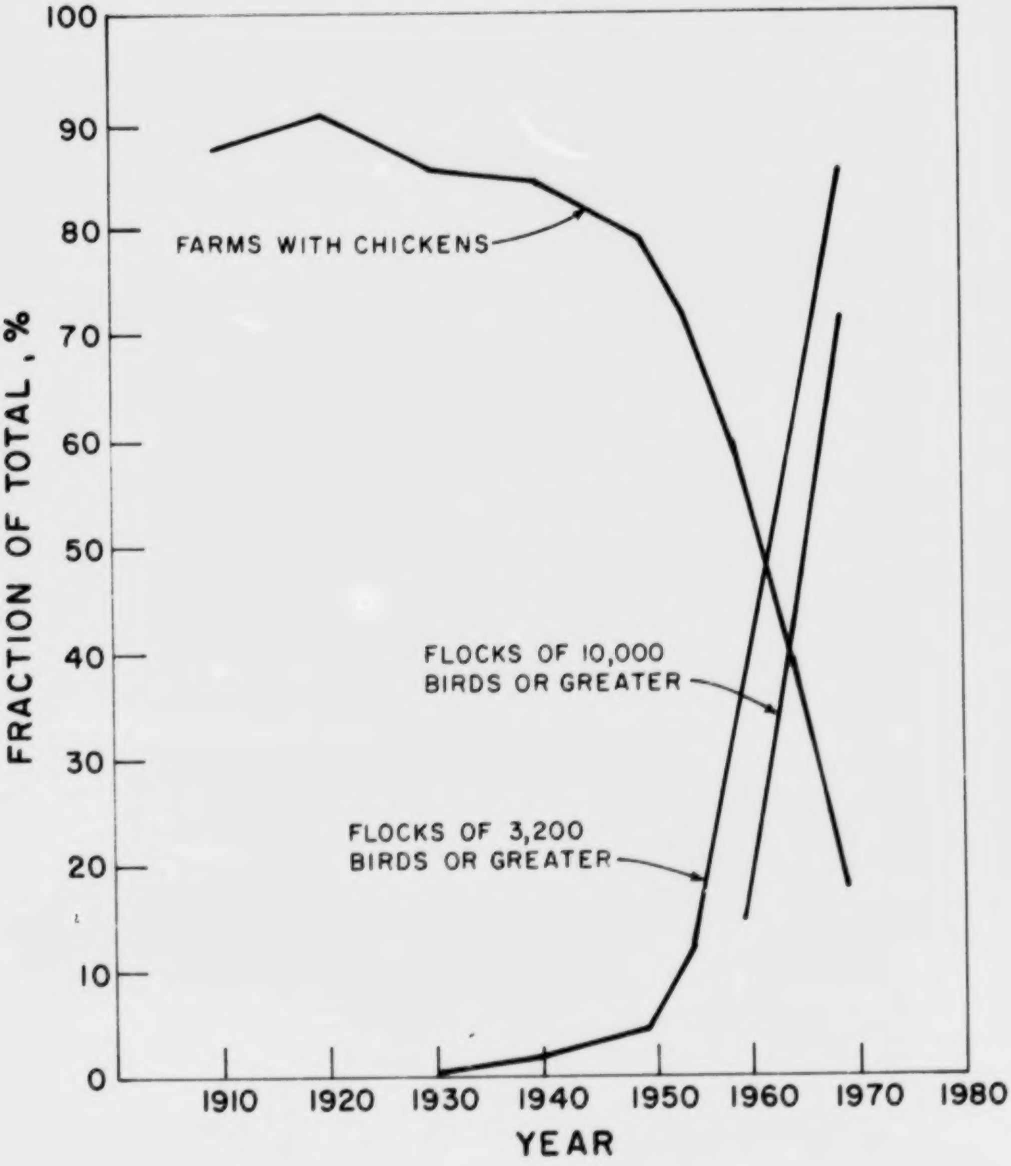


FIGURE 2. Changes in size of U.S. chicken production facilities with time (7)(8)(9)(10).

Integration

The egg industry has become more and more integrated in recent years in terms of its ability to be self sufficient from feed production through final product packaging and marketing. Using a new model procedure to measure integration (index of integration) a report published by the U.S. Department of Agriculture indicated lower egg production in regions where the rate of integration lagged and higher production in regions where it has been more vigorous (11).

The market egg industry is expected to become more highly integrated during the 1970's. However, differences between regions will become less pronounced and integration will have far less effect in causing regional shifts of output than during 1955-59.

Egg Products

The location of plants producing frozen or dried eggs in the United States is shown in Figure 3. Due to the mandatory application of the Egg Products part of the Egg Products Inspection Act in 1971 (12), the number of plants under official U.S.D.A. inspection has changed as shown in Figure 4. Comparison of Figures 1 and 3 confirms that plants producing egg products are generally located in areas of heavy egg production.

The number of egg breaking plants for selected years by regions in the United States is summarized in Table 1. The largest number of egg breaking facilities was 477 in 1949, with 152 in operation in 1972. Five plants were in production in New York as of June 1974.

The large number of facilities existing during the days of World War II resulted from government support programs. Dried whole eggs were included under the Lend Lease Program in the spring of 1941. The

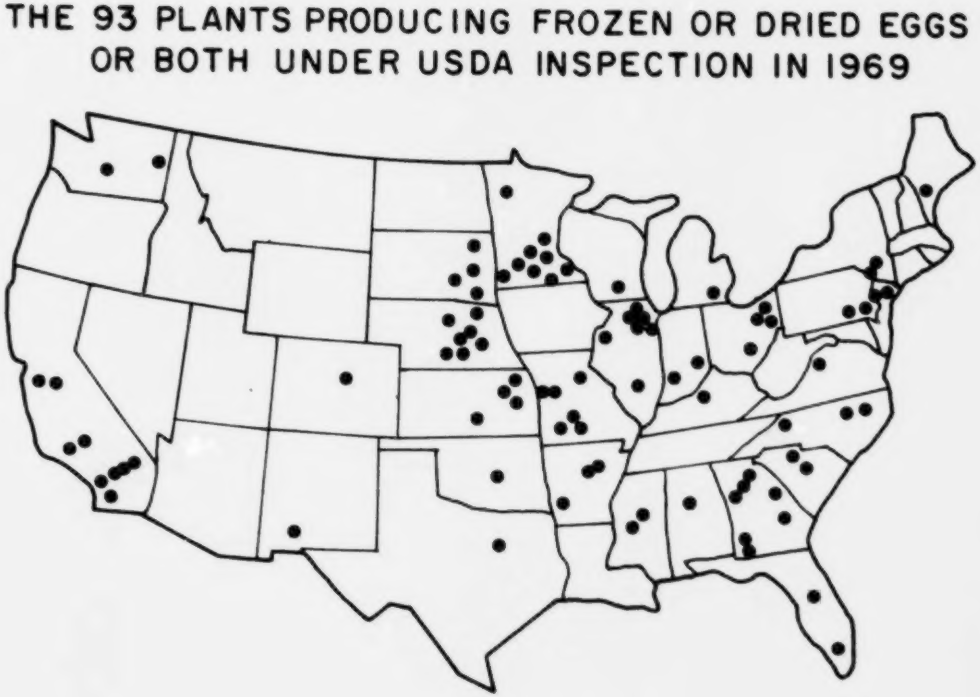

THE 93 PLANTS PRODUCING FROZEN OR DRIED EGGS
OR BOTH UNDER USDA INSPECTION IN 1969

FIGURE 3. Distribution of facilities producing frozen or dried eggs or both under U.S.D.A. inspection in 1969 (4).

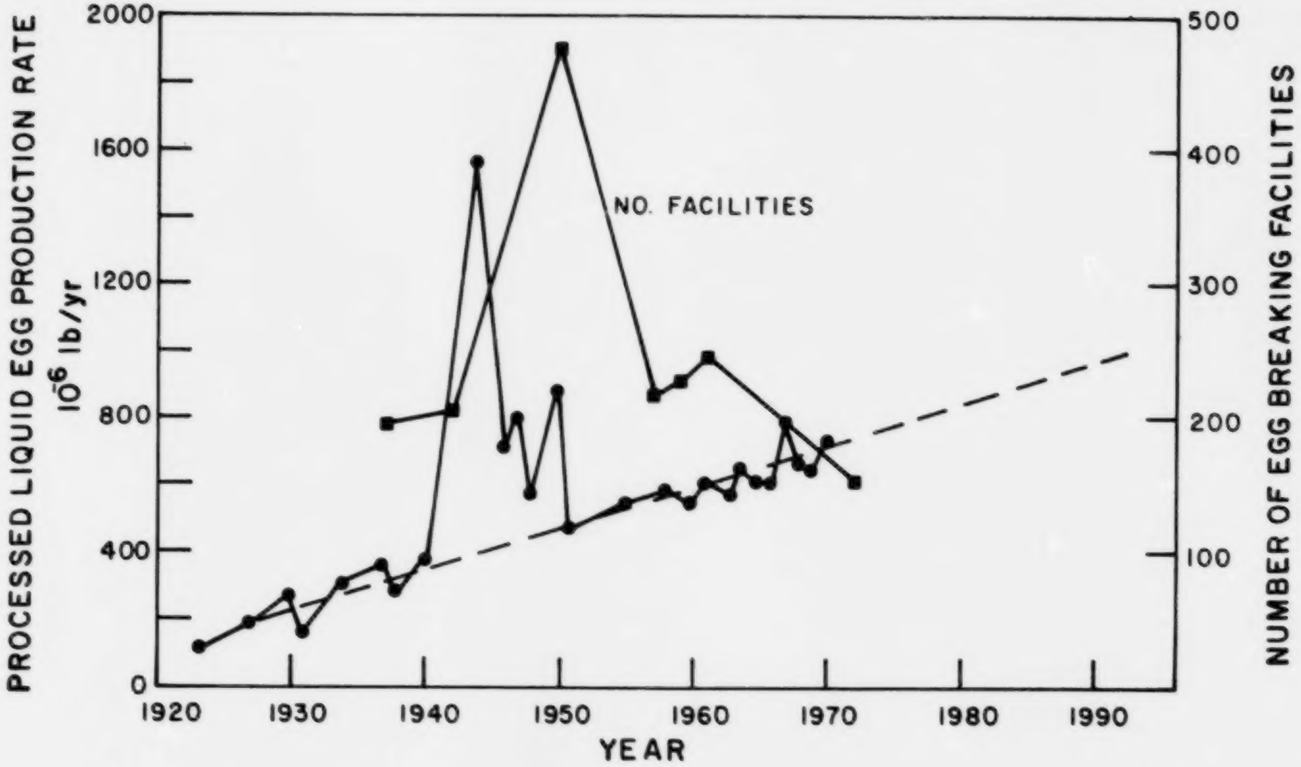


FIGURE 4. Annual U.S. production of liquid egg products (dried, frozen, and those used for immediate consumption) and number of plants under U.S.D.A. inspection (13)(14).

government then began to purchase shell eggs on the open market at supported prices to stimulate farm egg production and this stimulated construction of additional breaking and drying plants (13).

Table 1. LOCATION OF EGG BREAKING FACILITIES IN U.S. IN SELECTED YEARS (13)

Region	1937	1942	1949	1957	1959	1961	Sept. 1972	1972 compared to 1949: Changes in no. of plants	1972 compared to 1949: 1972 as a % of 1949
North Atlantic	23	17	48	26	39	35	25	-24	52
East North Central	36	26	80	40	40	46	22	-58	27
West North Central	78	87	213	98	96	89	38	-175	18
South Atlantic	1	2	13	5	11	23	17	+4	131
East South Central	4	8	13	4	4	6	7	-6	54
West South Central	24	29	55	8	6	8	5	-50	9
Western	30	26	55	32	31	41	38	-17	69
United States	196	205	477	213	227	248	152	-325	32

Without government purchase of dried whole eggs after 1950, many egg breaking plants were forced to close. The largest reduction in numbers took place in the West North Central States and the major percent decline was in the West South Central States.

After the Egg Products Section of the Egg Products Inspection Act became effective in 1971, the number of breaking plants decreased in all regions excepting the East South Central States. This decrease was due to economic and other pressures resulting from breakers complying with the regulations of the Act.

The production of liquid eggs doubled from the early 1950's to the late 1960's, reaching a peak of 800 million pounds in 1967. During this period about 5% was used for immediate consumption, 50% was frozen and 45% dried. As indicated in Figure 4 it is anticipated that the future growth trends of the egg breaking industry will be linear as extrapolated from the past. However, development of new products and markets may substantially increase the market for egg products. For example, the next section mentions the possibility of using significant quantities of egg white in new food products (Appendix B). If new applications such as ice cream production were developed the growth rate of this industry could approach large increases of 10 to 20 percent per year. The estimated growth in production capacity will be linear at about 12 million pounds per year, or 1.3 percent per year compared to present capacity.

Types of Liquid Eggs

About half the liquid eggs produced are whole eggs and mixed emulsions. Egg whites account for about 25% and the various kinds of yolks 25%. All classes of products showed upward trends from 1961-67, but they are not uniform. The whole egg, with yolks and whites in their natural proportions, was usually the largest class of product during 1951 through 1969. At times more whites were produced than whole eggs but in general whites were second to whole eggs in pounds produced. Yolks showed a strong upward trend from 1959-67 with a decline in 1968-69. Mixed emulsions trailed the other classes of egg products, but also showed an upward trend from 1951-67. In recent years sugared and salted yolks have been reported with yolk emulsions and the three products are now called "other yolk." In frozen form the greatest production was in whole plain eggs with yolk blends and whole blends next (4).

The difference in value between the various liquid egg products may indicate the source of some of the potential pollution problems. Separated egg whites are now selling for about $0.20 per lb., yolks for $1.00 per lb. with whole eggs selling for about $0.40. Not only is it difficult to detect losses of egg whites, but the economic incentive to conserve this material is low.

SECTION III

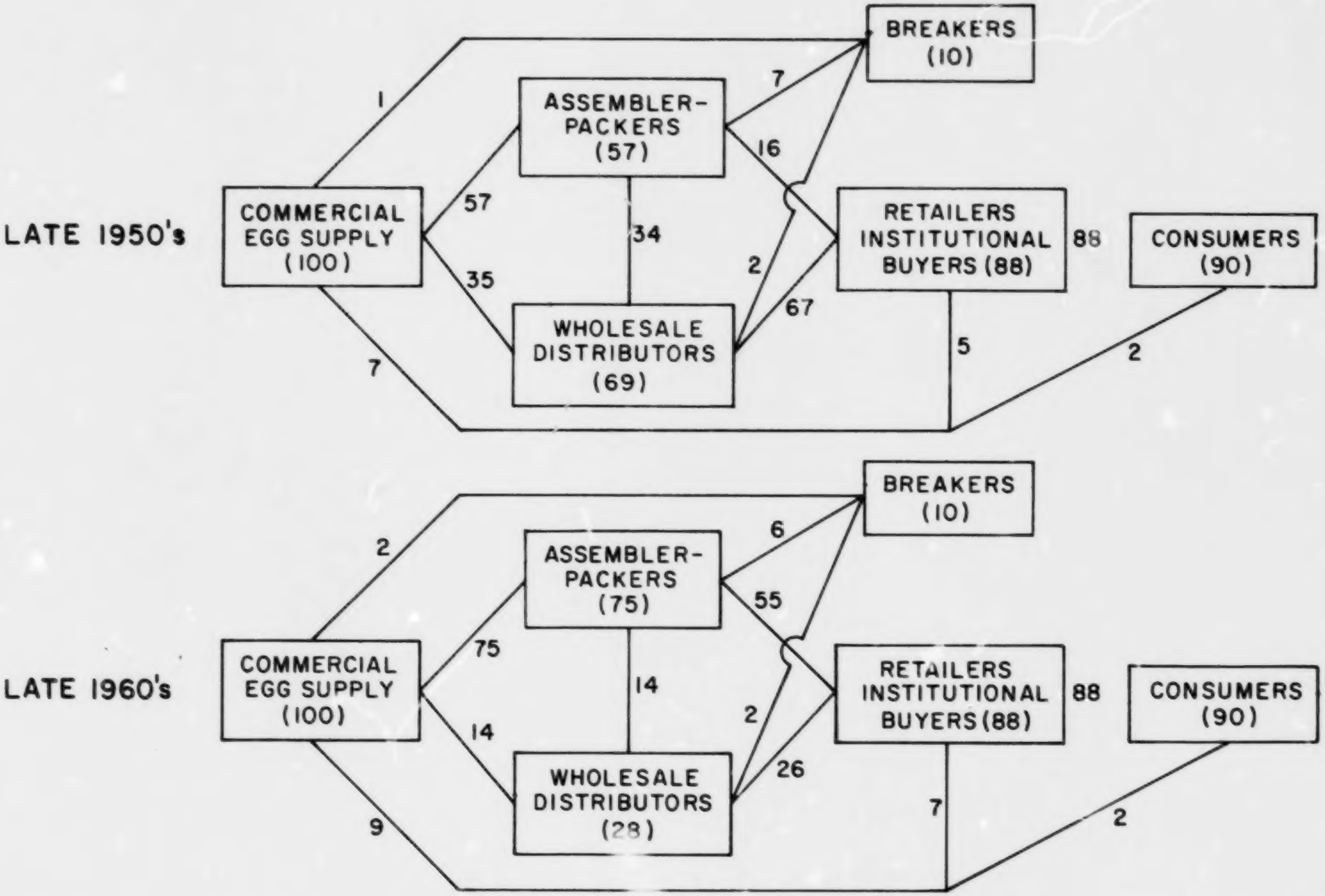
MARKETING CHANNELS

The commercial egg marketing channels in the late 1950's and in the late 1960's are shown in Figure 5. During that period market egg producers sold the bulk of their output to assembler-packers; wholesale distributors were the second most important buyers. The rest went directly to breakers or circumvented the major marketing channels and went directly to retailers, consumers and institutional outlets (15).

Egg breakers now get about 60% of their egg supplies from assembler-packers. Producers and wholesale distributors supply about 20% each. Once broken, the liquid eggs are eventually sold to firms using liquid, frozen or dried eggs in manufactured products. These products reach ultimate consumers through retail or institutional outlets (15).

During the last two decades, there was a drastic realignment of major marketing channels for shell eggs. The decentralization of grading and cartoning operations toward country points has been accompanied by expansion of direct deliveries to retail warehouses and stores by assembling and packing firms (which now include many more producer-packers). The latter development has meant that wholesale distributors in city markets have been increasingly bypassed. In ten years the share of the commercial market egg supply passing through the hands of wholesale distributors has been cut in half (15).

Egg breaking is conducted basically as a convenience in salvaging undergrades and disposing of seasonal surpluses of off-sized eggs. However, the present trends are moving towards filling orders on a regular basis the year around. In order to do this, breakers are buying eggs from outside the state when needed to supplement the state's supply.


LATE 1950's

LATE 1960's

COMMERCIAL EGG SUPPLY (100)
ASSEMBLER-PACKERS (57)
WHOLESALE DISTRIBUTORS (69)
BREAKERS (10)
RETAILERS INSTITUTIONAL BUYERS (88)
CONSUMERS (90)
1
57
35
7
34
7
16
2
67
88
5
2
COMMERCIAL EGG SUPPLY (100)
ASSEMBLER-PACKERS (75)
WHOLESALE DISTRIBUTORS (28)
BREAKERS (10)
RETAILERS INSTITUTIONAL BUYERS (88)
CONSUMERS (90)
2
75
14
9
14
6
55
2
26
88
7
2

FIGURE 11. Commercial egg marketing channels. Numbers indicate the percent of the total which follow a given pathway (15)

SECTION IV

PRODUCTION, CONSUMPTION AND PRICE

SHELL EGGS

Total egg production and domestic egg consumption in the United States trended upwards from 1953 to 1972, despite a corresponding decline in per capita egg consumption (Table 2.) During this same 20-year period, the average retail price trended downward. Relatively high prices occurred in 1969 and 1970 but were contrary to trend (6). The increases in total egg production and domestic egg consumption totalled 11% during the two decades. Total egg consumption is higher only because of the increase in populations.

Table 2. EGGS: PRODUCTION, CONSUMPTION AND RETAIL PRICE IN THE UNITED STATES FROM 1953 TO 1972 (6)

Year	Total egg production	Domestic egg consumption	Per capita consumption	Retail price per dozen of Grade A large egg
	Mil. dozen	Mil. dozen	Number	Cents/doz.
1953	5,307	4,928	379	69.8
1962	5,403	4,998	327	54.0
1972	5,897	5,421	315	52.4

EGG PRODUCTS

From 1951 to 1969, the fraction of the total eggs used for breaking has almost doubled. This figure increased from about 6% of all eggs produced in the early 1950's to nearly 10% in the late 1960's (Table 3). During the same period wholesale selling prices of frozen eggs showed a downward trend. However, the estimated value of liquid eggs produced increased from about $130 million early in the period to nearly $200 million by the late 1960's (4).

Liquid egg production doubled from the early 1950's to the late 1960's resulting in a peak of 800 million pounds in 1967. Trends were: a small increase in percentage of liquid eggs used for immediate consumption, a decrease in the percentage of liquid eggs being frozen from about two-thirds of total liquid production early in the period to about one-half late in the period and an increase in the percentage of liquid eggs being dried from about 15% early in the period to nearly 40% in later years (4).

PRODUCTION RATE VARIABILITY

In considering pollution control in this industry one of the most important characteristics is the high variability of production rate. The history of this industry revealed that in its early development it was essentially a scavenger industry operating off surplus egg production at times of the year when shell egg production was depressed. Although the industry presently competes for good quality eggs throughout most of the year or imports the needed amounts, it is still highly susceptible to availability of supplies and the market. The data shown in Figure 6 illustrates this variability in the U.S. over a three year period and Figure 7 summarizes this data for one of the larger facilities sampled in this study. The whole industry faces shortages of raw material during the winter months of November and December and usually experiences a maximum production in the late spring and early summer. A wastewater treatment facility must be designed to handle peak loads during the period April through June, and be capable of efficient operation at only half the waste load during the period November through January.

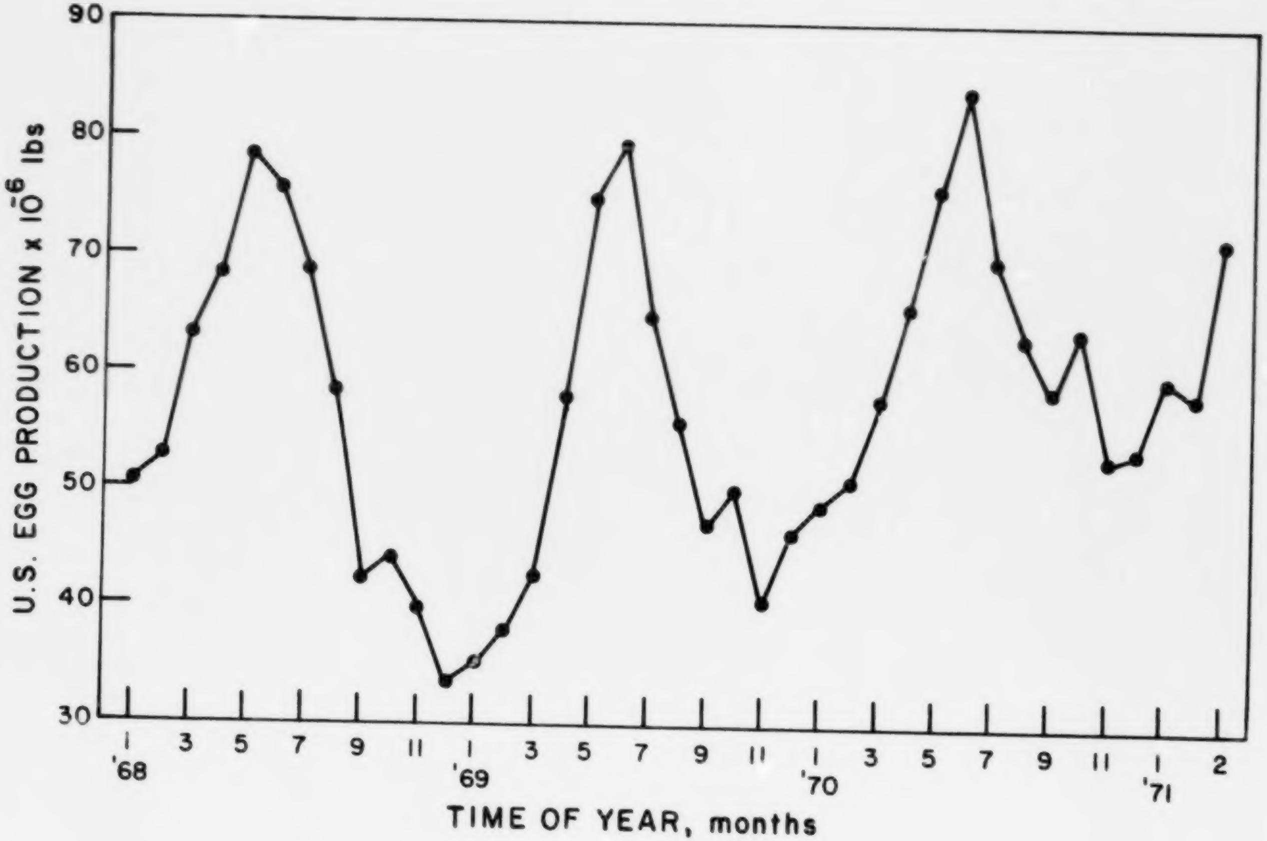


FIGURE 6. Monthly variations in United States egg product production (immediate consumption, frozen, dried) (16).

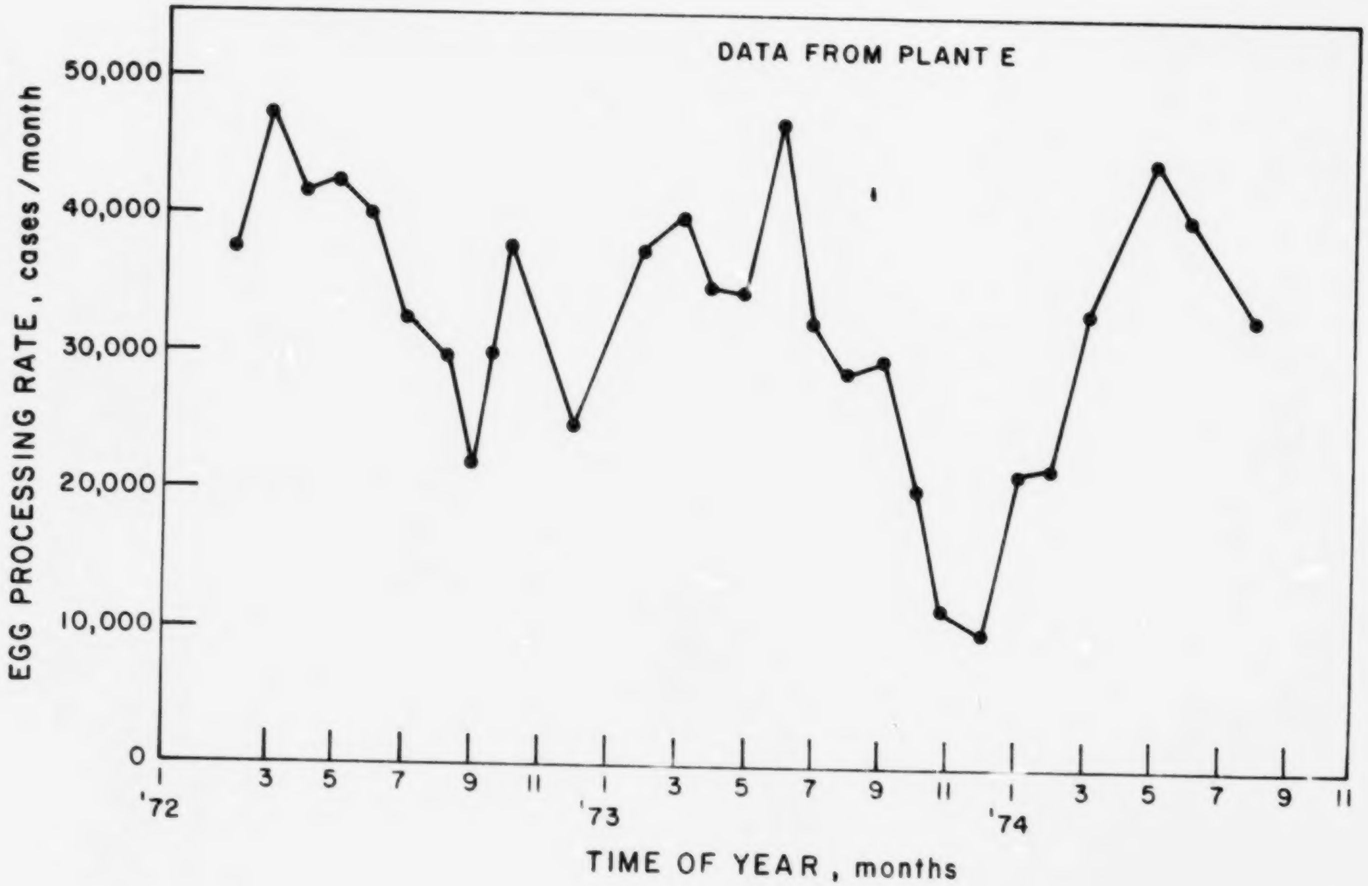


FIGURE 7. Monthly processing rate of eggs at Plant E.

Table 3. EGGS USED FOR BREAKING: NUMBER, LIQUID EGGS PRODUCED, WHOLESALE SELLING PRICE OF FROZEN EGGS, AND ESTIMATED VALUE OF LIQUID EGGS PRODUCED IN THE UNITED STATES DURING 1951-69 (4).

Year	Eggs used for breaking		Liquid eggs produced	Eggs used for breaking as a percentage of total egg production	Wholesale selling price of frozen eggs at New York City[b]	Estimated value of liquid eggs produced
	10^6	(10^3 cases[a])	(10^6 lbs)	(%)	(cents per lb)	($1000)
1951	3,821	10,614	409	6.6	34.8	142,332
1959	6,389	17,755	701	10.1	26.0	182,260
1960	5,310	14,746	582	8.6	27.9	162,378
1965	5,730	15,919	629	8.7	25.7	161,653
1969	5,836	16,212	640	8.5	30.5	195,200

[a] A case contains 30 dozen (360) eggs.

[b] Poultry Market Statistics, Consum. and Mktg. Serv., U.S. Dept. of Agr.

USES OF EGG PRODUCTS

Egg products are used mainly by bakers, confectioners, premix manufacturers, and food manufacturers of baby foods, noodles and macaroni, mayonnaise and salad dressings, ice cream and a large variety of other food products. Only during World War II and relatively recently have egg products been available in packages of a size for home use.

Different types of "egg" are used for producing certain food products because of their different functional properties. For example, egg whites, yolk and whole egg are used for producing many food items because of their texture and flavor.

SECTION V

HISTORICAL AND TECHNOLOGICAL DEVELOPMENTS AND THEIR RELATION TO OPERATING PROBLEMS

There have been many developments of a historical and technological nature which have resulted in improved products and greater production and marketing efficiencies within the egg industry (17). Space does not permit a detailed discussion of each development. However, considerable insight into the rationale for some of the activities of the industry can be gained by review of significant developments. A listing has been included in the Appendix.

PROBLEMS IN EGG PROCESSING PLANTS

There have been many developments that have improved the product and increased the operating efficiency in egg processing plants. However, some of these improvements have resulted in, or contributed to, problems now encountered in processing plants. Different parts of the egg contribute to some of the difficulties encountered in these plants.

In order to better understand why and how the egg contributes to egg processing plant problems, knowledge of the egg is desirable. The composition of the egg gives some background to a better understanding of the potential pollution problems. For additional detailed biological and chemical composition of eggs see Stadelman and Cotterill (18).

THE EGG

Structure

The parts of an egg are shown in Figure 8. The yolk comprises about 31% of the total weight of the egg and the white around 58% of the egg

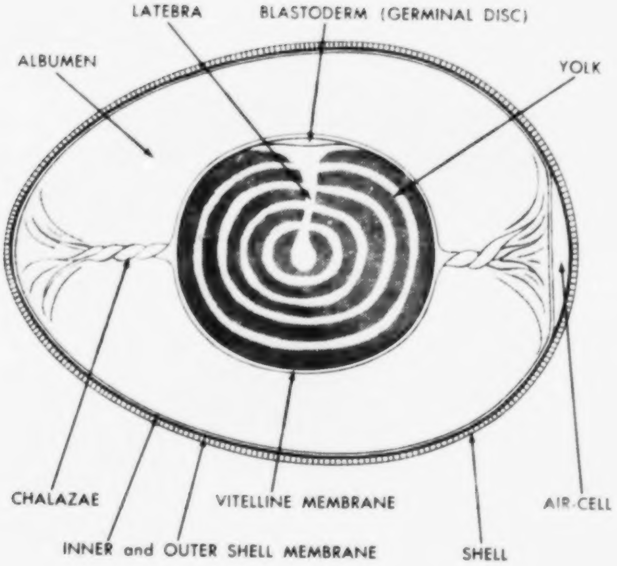


FIGURE 8. The parts of an egg (19).

weight. The chalaziferous layer of the white represents about 3% of the total white (albumen). The chalazae is white fiber that is removed from the liquid egg material by a screening process. In some cases these screens may be cleaned by hosing the material off into the sewer. As will be noted in the following section, this is a practice which loses a salable product and should not be continued.

There are two shell membranes. The inner and outer membranes together are only about twenty-four ten-thousandths of an inch thick. These membranes adhere to the shell in the breaking process along with some albumen. The shell constitutes approximately 11 percent of the egg and is composed of about 94% calcium carbonate, 1% magnesium carbonate, 1 percent calcium phosphate and 4% organic matter, chiefly protein. There is a general industry "rule of thumb" which assumes that 83% of the total weight of an egg ends up as liquid egg. This would therefore indicate that 6% of egg liquid remains on the broken shell. This liquid material may be worth recovering in some instances.

Composition

The protein of the egg contains all of the indispensable amino acids in well balanced proportions for human consumption. Both the thick white and the thin white are made up of the same proteins, excepting ovomucin which is contained only in the thick white. The other proteins contained in each include ovalbumen, canalbumen, ovoglobulin and ovamucoid. The ovomucin gives the structure to the thick albumen.

The important yolk proteins include ovovitellin (about three-fourths of the yolk) and livetin. The fatty substances of the yolk are mostly glycerides (true fat), lecithin and cholestrol. Lecithin helps give the yolk its emulsifying properties. The percentage composition of the egg is given in Table 4.

Table 4. COMPOSITION OF AN EGG (19)
(All values in percent by weight)

		Water	Protein	Fat	Ash
Whole egg	100	65.5	11.8	11.0	11.7
White	58	88.0	11.0	0.2	0.8
Yolk	31	48.0	17.5	32.5	2.0
		Calcium Carbonate	Magnesium Carbonate	Calcium Phosphate	Organic Matter
Shell	11	94.0	1.0	1.0	4.0

The fat or oily materials in the egg are important in relation to pollution control because of the regulations on these materials in effluents. However, effluent concentration regulations are intended to limit grease, oils and fats that are petroleum base materials. Animal and vegetable fats may not be susceptible to these same regulations. One precaution should be noted. This material may coat the surfaces of treatment units and clog valves and pipes. These coatings may turn septic and cause very undesirable odors.

SOURCES OF EGGS FOR PROCESSING

Most of the eggs that are purchased by producer-processors and commercial processors (dealers) are obtained from farms that keep their hens in laying cages. This means that such eggs are usually clean. However, there are still farms, from which these processors purchase eggs, that have floor operations. This means laying nests and nesting materials which provide opportunities for the eggs, lain in the nests, to more readily have feces and nesting materials on them when they are exposed to processing.

Producers who sell eggs market them in one or more of the following forms:

1) "Nest run" - Just as they are gathered or collected from cages or nests). They include all sizes and qualities and are processed later for sale.
2) Washed - Some producers sell eggs, after washing and packing, to commercial dealers or other processors.
3) Washed and graded - Some producers sell eggs that are washed, graded (for weight) and packed to commercial outlets.
4) Fully processed - Many producers, particularly in states such as New York, wash, candle (for quality), grade (weight), and pack eggs in cartons or loose in cases to outlets such as stores, restaurants, bakeries, etc.

Egg breakers buy from producers, dealers, other breakers, etc. In New York State many of the eggs they buy from these people are "nest run" eggs. Breakers also buy undergrades such as checks, dirties, stains, odd sized and shaped eggs, rough shelled eggs, etc. While such eggs might be undergrade, insofar as the shell is concerned, many of them are of high interior quality.

Breakers also buy top quality shell eggs when they are available at a discount. To satisfy the demand of some users, for top quality egg products, breakers are now buying more high quality shell eggs regularly than they used to 10 or 15 years ago. Although it is a federal requirement that all eggs be washed, it is possible that when breakers are processing "once washed" high grade eggs and other clean products that washing may not be necessary. This issue is discussed further in Part II of this report.

PROCESSING PROCEDURES

A simplified processing diagram for shell eggs and egg products indicates the amount of handling to which eggs are exposed (Figure 9). These procedures vary according to how the processor is going to dispose of his eggs or product and other factors.

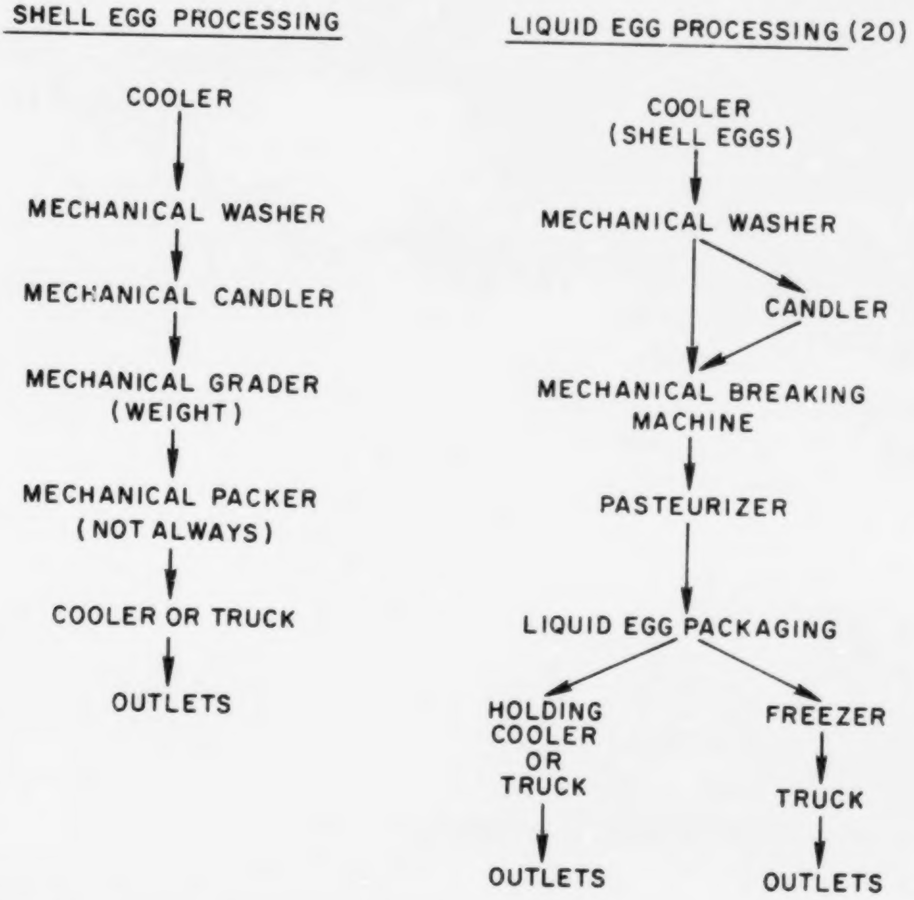


FIGURE 9. General steps in processing of shell eggs and egg products

PROCESSING WASTES

In both shell egg processing plants and in egg breaking plants the volume of waste is directly proportional to the volume of eggs or product produced and the handling procedures. In farm and commercial egg processing plants the wash water is often disposed of on land areas or subsurface without runoff, pollution or other problems. Fiber and plastic products (damaged cases, cartons, etc.) are taken to landfill areas.

The undergrades (checks, dirties, stains, etc.) are sold at the farm or plant, or to egg breaking plants within the limits outlined by the Egg Products Inspection Act (12). Certain restricted eggs as outlined in the Act, are used for animal food. Those that are illegal to use for human or animal food are disposed of according to the instructions of the Act.

PROBLEMS IN SHELL EGG PROCESSING PLANTS

The same general type of problems exist in both shell egg processing plants and in egg breaking plants. The problems in both types of processing may be categorized into three broad areas; economic, functional and legal. Since there are some differences between the problems existing in shell egg processing plants and in egg breaking plants they are considered separately.

It might be said that the major problem in processing plants today is a lack of accurate knowledge of where and what the specific problems are and how important they are. For example, in shell egg plants, studies conducted in 17 farm processing plants show that the average loss from shell damage and poor shell texture alone was 9.3% (21). Of this 5.8% was due to shell damage (checks and leakers). Table 5 shows these losses in percent and the estimated cost of such losses to the shell egg industry in New York State in 1973.

Table 5. ESTIMATED LOSS FROM SHELL EGG DAMAGE AND POOR TEXTURE IN NEW YORK STATE PROCESSING PLANTS, 1973 (21).

	Shell damage or Texture loss (%)	Loss ($)
1) Processing damage		
a) checks	4.1	1,470,875
b) leakers	1.7	1,545,017
2) Unaccounted for in processing	3.0	2,726,500
3) Eggs downgraded to B quality because of poor textured shells	0.5	51,250
TOTAL		5,793,642

The amount of "egg breakage" in shell market plants depends upon many factors which include handling, strength of eggshells, environmental conditions, etc. Handling is a very broad term which not only connotes "rough handling" by workers but by materials handling and processing equipment which had been developed to improve the operation efficiency in the plants. Automatic packers are often the worst offenders in connection with physical damage, sometimes causing shell damage amounting to 20% of total damage between the time the eggs leave the washers and the time they are placed in the egg cartons.

Wastewater Contaminants

The contents of the eggs contaminate the wash water and are found in the effluent being discharged from the plants. Any increase in egg solids in the wash water will increase the BOD (biochemical oxygen demand) requirements for reduction of wastes to a level acceptable by authorities. A summary of other contaminants and waste problems are:

-Foreign materials from eggs - feces, pieces of nesting materials (on eggs from floor operations), feathers, etc.

-Pieces of fiberboard (from egg cases), paperboard and plastic (from egg cartons), inedible eggs, etc., are problems in that they must be disposed of properly. This contributes to the cost of operating the plant.

-Accumulation of "shell sand" (fine dust from shells), that filters down through the screens under the washers, clogs traps in the drainage systems.

-Too much water used in a processing plant.

-Disposal of effluent coming from the plants is a major problem. Depending upon the soils, terrain and the possibilities of pollution of air or water, various treatments are utilized to reduce the BOD (biochemical oxygen demand) of the effluent and odors to an area. These may include daily trucking of the effluent to spread on land, aeration-oxidation of the effluent, municipal disposal systems or others. None of these treatments have been entirely satisfactory for every plant.

-Employees of processing plants are not informed of the pollution potential of eggs lost to the floor, of pieces of egg cases and cartons, of other foreign substances, etc. Thus, there is little effort made to reduce such losses.

-Plant managers themselves do not attempt to monitor or study the amount of product lost to the floor, or the amount of foreign materials reaching the floor to drainage systems. They, therefore do not know what these losses cost them.

PROBLEMS IN EGG BREAKING PLANTS

In a recently completed survey of wastewater problems in all egg breaking facilities in the U.S. it was reported that nearly half the respondents have wastewater disposal problems (22). About two-thirds of the total were served by municipal sewers and the remainder by some type of private system. The most common individual facility wastewater treatment system reported was the septic tank.

Similar problems listed earlier for shell egg processing plants also apply to egg breaking plants. Shell egg breakage from washers in breaking plants would be greater than that from washers in shell egg processing plants because more checks (crax) and weak-shelled eggs (salvage) are put through the washers in breaking plants. Several breaking plant operators in New York State estimated their losses from egg breaking activities to be between 6% and 10%. In some instances breaking plants were working under contracts which committed them to pay for only those eggs that were actually broken. Thus those losses which occurred in handling and washing prior to breaking did not represent a loss to the processing facility. Such agreements are counter productive to pollution control and should be discouraged.

One of the common problems in egg breaking plants is the loss from product overflow. It was estimated by one worker that egg losses could be reduced about 50% by improved floor management which would stop losses such as product overflowing from vats and the salvage of animal grade foods from areas like auger drippings.

Egg breaking machines are designed so there are no provisions made to catch drippings from the machine cups as they travel around the "breaker." Simple collection devices would convert this type of pollution into a salable product such as animal food.

Waste treatment systems can be simplified if the more concentrated wastes are segregated and controlled. While there are some attempts for plant management to salvage some low grade egg products for animal foods, the value of this approach for plant management is presently underestimated.

Pasteurizing liquid egg in a plate-type pasteurizer is similar to that for milk except that lower temperature and more time is required. After such pasteurization the plates and pipes are still full of liquid eggs and must be "chased" or flushed with water. If the "chasing" is not done thoroughly or properly the loss to a small breaker could represent a considerable amount of his total input (20). Part II of this study will discuss management approaches to controlling or minimizing the wastewater generated by the previously mentioned problems.

PROBLEMS CAUSED BY EGG BREAKING FACILITIES

As was noted earlier, egg breaking facilities are distributed throughout the U.S. and located in many small rural communities. The relationship of the magnitude of the wastewater disposal problem to the community sewage problem can be illustrated by comparing the sizes of the five communities tested in this study to other community characteristics (Table 6). The average waste discharged from the facilities varied over an 80 fold range. Conversion of the organic waste generated to a human equivalent indicated that these industries produced wastes equivalent to sewage generated by communities varying in size from about 180 people to nearly 12,000. Comparison of this to the organic wastes generated by the population and other industries indicated that the egg breaking facility waste comprised between 8 percent and 1500 percent of all other wastes. In all five cases the management was concerned, and the problems ranged from the possibility of legal closure of the business to the cost which they were paying to obtain permission to discharge to the municipal wastewater system.

Table 6. COMPARISON OF EGG BREAKING PLANT WASTEWATER PROBLEMS TO THE SURROUNDING COMMUNITY SEWAGE PROBLEM FOR FIVE FACILITIES

Breaking plant	Egg breaking waste discharge lb. BOD$_5$ per day	Sewered population and additional industry in community	Waste contributed by population and industry[a]	Type of treatment system in community	Egg Breaking Waste % of total $\left[100 \times \frac{\text{lb BOD}_5\text{ plant}}{\text{lb BOD}_5\text{ remainder of community}}\right]$
A	104	1400 people no industry	280	trickling filter	37
B	258	700 people no industry	140	trickling filter	184
C	35	-- no industry	-	no existing treatment plant	--
D	2436	800 people 2 pipe manufacturers	>160 unknown quantity by pipe manuf.	oxidation ditch (under construction)	1520
E	938	21,000 people 4-poultry & turkey processors 1-sweet potato canning operation	11,930	high rate trickling filter	7.8

[a] Assume 0.2 lb BOD$_5$/capita/day

SECTION VI

FUTURE OF THE EGG INDUSTRY

SHELL EGGS

In the next 10 years the number of hens in the United States should remain rather stable at not over 300 million. In 1973 there were about 292 million hens in the continental United States (1).

Projections indicate that the output of eggs in the United States is likely to be between 76 and 84 billion eggs in 1985. This is based on an assumed production level of 317 eggs per person per year and population projections that range from 240.7 million to 263.0 million people.

Part of this increase in production will be the result of an increase in the rate of lay per hen. This statement is based on an expected rate of lay of 250 eggs per laying hen, per year, which seems statistically reasonable and physiologically possible (23).

The figure of 317 eggs per person was based on the observation that during the years between 1962 and 1970 supplies at levels near 313 eggs per person have resulted in very favorable prices to producers, while supplies near 322 have resulted in quite unfavorable prices. The equilibrium level is likely to be somewhere between. About halfway would be 317 eggs. Actual consumption may eventually drop below 317 eggs per person, however, unless innovative ideas are generated to maintain markets and new uses for eggs (23). The consumption of eggs was 292 per person in 1973 with a high during the past 10 years of 324 eggs per person in 1967 (1).

The trend of a decreasing number of commercial egg farms and an increase in the size of those farms will continue during the next 10 years but not as rapidly as during the time between 1964 and 1969. During this period the number of farms reporting chickens decreased by over 61%, even allowing for an extra month of age (3 months old and over instead of 4) in 1969.

Factors that may restrain egg production expansion are those that arise as an area urbanizes; problems of odor and waste disposal. The egg industry will need to locate in areas where such conflict can be minimized and they must find economical ways to control odors and dispose of waste (23).

Under existing conditions of production and distribution, New York producers within 150 miles of a major market can probably maintain their present level of output, but producers in more distant regions, like the northern part of the state, cannot compete (23).

EGG PRODUCTS

Such factors as weight consciousness, health and highly advertised breakfast cereals, which have helped to affect a decrease in per capita shell egg consumption may increase the per capita consumption of egg products in the future. The office workers who do not eat breakfast, but have pastry and coffee at morning breaks are eating more processed eggs. A homemaker who bakes a cake from a pre-mix is using such eggs. Restaurants, hotels, and institutions frequently use processed eggs because of the convenience. As the number of meals eaten away from home increases, so does processed egg consumption. These factors alone would assure continued growth of the egg products industry (4).

However, an additional market potential exists in new consumer products that are being developed. If more and more of these products are accepted, per capita consumption of egg products is likely to offset the expected decrease in consumption of shell eggs and will stabilize the per capita consumption of all eggs.

Projections of production and prices for egg products were made by Jones (14). He projected quantities of 1.0 billion pounds for 1975 and 1.3 billion pounds in 1980. Reference to Figure 4 indicates that these values are high according to this data. He estimated the value of egg products to be $260 million in 1975 and $318 million in 1980.

As with other trends in the egg industry egg breaking plants are becoming fewer and larger. If the present trends continue the number of egg breaking plants in the United States will drop from 152 in 1972 to an estimated 108 in 1985. The number of breaking plants in New York State conceivably could be reduced from 5 (1 plant part time) to 1 or 2 by 1985. These larger egg breaking plants will have increased problems with waste disposal and odors than do the smaller plants now in existence.

PART II

CHARACTERISTICS OF EGG BREAKING AND PROCESSING WASTES BEFORE AND AFTER IN-PLANT WASTE REDUCTION

SECTION I

INTRODUCTION

GENERAL

Disposal and treatment of wastes from egg breaking plants seriously trouble the poultry industry. Historically, egg wastes were troublesome to treat, but the disposal of the residuals is now further complicated by upgraded sanitation edicts in the Federal Egg Products Inspection Act of 1970. It has been estimated that about 4 to 25% of all egg breaking stock is wasted to sewers (22).

LOCATION

Five egg processing plants were examined in this study. Three were smaller plants located in upstate New York, and two larger egg breaking operations were briefly visited and sampled in Georgia and Arkansas. Four of the five plants discharge their wastewater to municipal treatment facilities and the other has its own state approved system.

The three New York plants were studied in greater detail than the other two. A minimum of six days of 24 hour sample collections were used in the New York State facilities to define the wastewater characteristics to enable reliable estimations of the waste loads before and after in-plant modifications. Two days of sampling were needed to develop data for each of the two plants outside New York. Eighteen days of sampling provided information on waste characteristics for the most intensively examined facility.

PROJECT APPROACH

All plants were examined for total plant losses as well as unit process losses in order to identify in-house sources of waste. Methods to reduce wastes through in-plant modifications were suggested and implemented. Later, the sites were sampled again to measure the effects of the changes through repeated plant wastewater surveys.

The wastes were physically, chemically, and biologically characterized to provide data for treatability studies.

Waste and water from all plants were compared on an equal basis to determine the relationship between plant size and magnitudes of product losses and water usage.

SECTION II

FIELD STUDY DESCRIPTION

DESCRIPTION OF PROCESSING PLANTS

A summary of the equipment used and type of product processing performed at the five plants surveyed is contained in Table 7. Independent of the plants' size, it was observed that the plants' layout and mode of operation were nearly identical. The flow diagram of an egg breaking operation in Figure 10 illustrates the various operations involved in preparing liquid, frozen or dried egg products from shell eggs. The first step in the operation is receiving the cartons of eggs from shell egg distributors. The eggs, which may have come from a distributor within a thousand mile radius, are stored in a cool humid climate to maintain egg freshness and minimize evaporation of water from the egg contents. Figure 11 is a photo of good quality nest run eggs in the storage area of Plant D. Egg cases, containing 15, 20 or the more usual 30 dozen per case, are manually loaded onto a system of rollers which carry them to the egg washer.

Upon reaching the washer, eggs are manually loaded onto a conveyor belt of rubber rollers. It is the duty of the person at this point of the operation to inspect the eggs and remove any "leakers" which are broken shell with contents exposed. Once a case of eggs has been loaded onto the washer, the empty cartons and filler flats are set aside to be returned to egg distributors, bailed for sale as scrap paper products or trucked to a sanitary landfill site. As the eggs move through the washer they are scrubbed by brushes moving in a vertical direction. At the same time warm water is being pumped from the washer's holding tank and sprayed across the surface of the eggs. This water contains detergents, defoaming agents, egg solids, egg shells and foreign material removed from the shell surface. The washing equipment contains about

Table 7. SIZE AND TYPE OF EGG PROCESSING PLANTS SURVEYED

Plant identification	No. of egg washers	No. of egg breakers	No. of egg pasteurizers	Type of product processing
A	1	1	1	Frozen yolk, white and whole egg
B	2	3	1	Frozen yolk, white and whole egg
C	1	1	1	Frozen whole egg, liquid whole egg (bulk tank)
D	12	12	3	Frozen whole egg, dried, yolk and white and whole egg
E	8	8	2	Liquid, yolk, white and whole egg (bulk tank transport as liquid)

a 50 gallon volume which is continually recycled for a four-hour period and then drained to the sewer system. The cleaning equipment is then refilled for another four hour egg breaking period. Once the eggs have passed through the scrub brushes they are conveyed above a series of brilliant lights for inspection in a candling operation. At this point inspectors remove leakers, blood spot, broken shells from eggs whose contents have been lost to the washer and eggs of poor interior quality. These inedible eggs are collected in segregated large containers for pet food products. It is also at the candling location that dirty eggs are

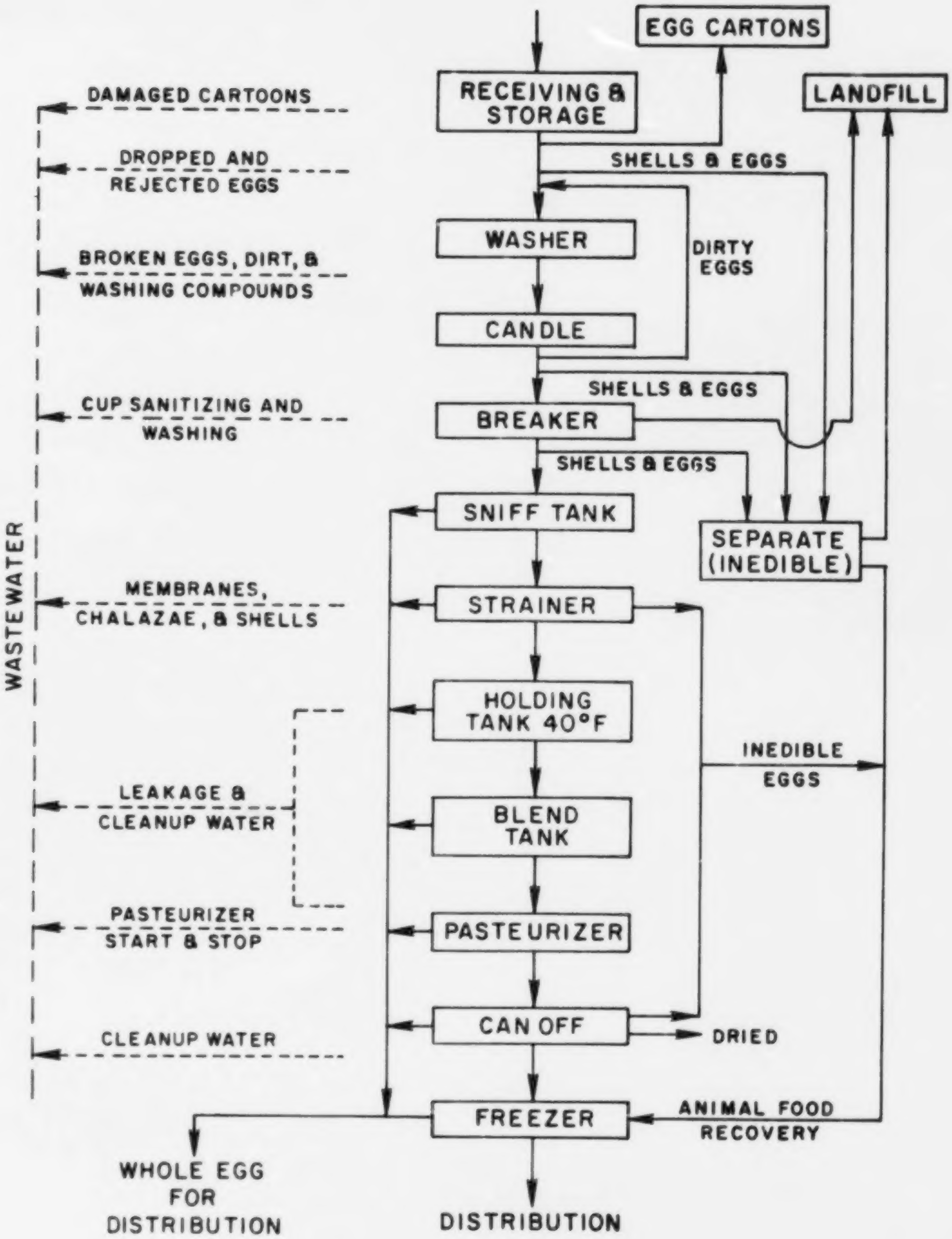


FIGURE 10. Flow diagram of product in egg breaking facilities.

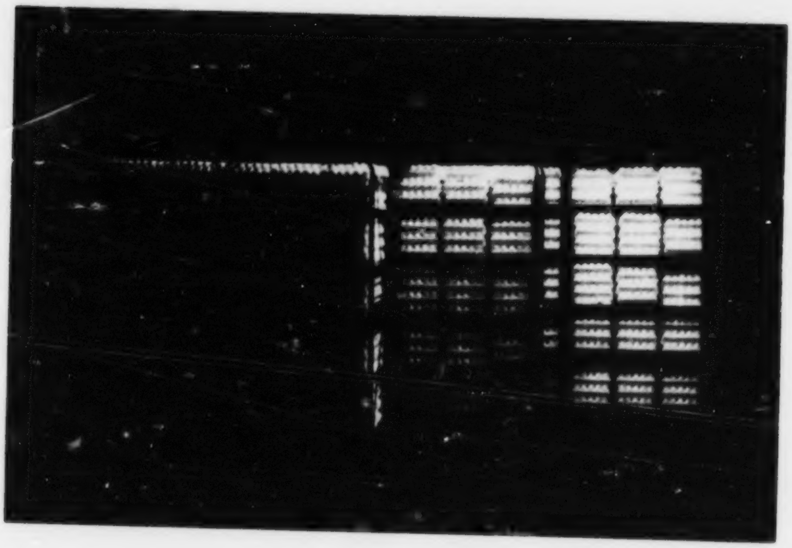


FIGURE 11. Egg receiving storage area for Plant D with clean "nest-run" eggs.

FIGURE 12. Egg breakers in Plant D.

removed to be rewashed and at the same time places exceptionally clean eggs onto the conveyor belt where vacancies exist. Just before the eggs enter onto the breaking machine they are rinsed with a chlorine spray containing 150-200 mg/ℓ chlorine. This rinse along with a spray rinse which preceeds the scrub brushes constitute a continuous overflow of water from the washer.

Eggs are automatically loaded onto a rotating egg breaking machine. Figure 12 shows the 12 breakers in operation at Plant D. The contents separate from shells and fall into stainless steel cups which are tilted forward to allow the egg white to drain from yolk portions into a second cup. As the cups move around the machine they are tripped to either collect yolks and whites separately or tripped to combine the two portions into whole liquid eggs. As the breaking machine continues rotation, the empty egg shell discharges from the machine by a strong air blast. After shell rejection, the mechanism which held the shell is automatically sprayed with water in preparation for receiving the next whole egg.

Breakers in plants cooperating with this study operated at a rate of 40 cases/hour which means that the employee at this machine must examine eggs at a rate of 4 per second. The employee operating the breaking machine has the responsibility to 1) remove eggs containing blood spots, 2) remove spoiled eggs and the cups into which they were broken, 3) manually break open any eggs which were not broken by the machine, 4) remove shell fragments which fall into the egg contents, and 5) trip the stainless steel cups to a full down position to be washed when they appear dirty or when no egg was released into the cups. If the USDA inspector notices dirty eggs on the breaker he may stop the operation and order the complete machine cleaned. If the plant is not adequately equipped for pollution control all the contents of the egg breaking machine at this point may be washed into the sewer instead of being saved for animal food or some other by-product.

Egg meats from the breaking machine operation collect in a small surge vat, and are pumped from the small vessel to a large sized sniff tank. The resident USDA inspectors require that this tank's drainage valve be closed until the sniff tank is full. After the sniff tank is physically examined by smell to be sure the product does not possess obnoxious odors, sugar, salt, and other condiments may be added to the product. The contents are drained through a coarse screen filter which retains shell fragments and the egg's chalazae. Food grade pumps transfer egg product from the strainer to a refrigerated holding tank (4.4°C).

Once enough product has been collected to ensure continuous pasteurization, it is pumped as a batch from the holding tank to a different blend tank where condiments or preservatives are added, if they were not added previously. When additives are not used the blend tank is by-passed and the product is sent directly to a small balance tank which preceeds the pasteurizer. Plate pasteurization requires temperatures ranging from 56°C to 63°C and holding times from 3.5-6.2 minutes depending on the type of product processed.

The pasteurized product is cooled to 4.4°C in a closed system of cooling plates from which it is pumped to a separate sanitary can-off room. Automatic filling machinery is used in this room to package egg meats in 13.6 kg (30 lb) cans, 1.9 liter (1/2 gallon) cartons or 4.5 kg (10 lb) plastic bags. Filled containers are prestacked on pallets in such a manner as to allow free circulation of air because the pallets are to be placed in freezer area. Freezing the final product prevents product degradation through bacterial growth from post-pasteurization contamination which in turn would require reprocessing.

The daily clean-up operations are one of the main sources of wastewater generation. Before work starts in the morning, the resident USDA inspector examines all machinery and its surroundings to be sure it is thoroughly cleaned and free of egg solids from the previous day's work. The breaking machine, all vat pipes and pumps are sanitized with chlorine solutions prior to beginning the process. After four hours of operation, plant production is stopped because microbial buildup occurs and sanitary rules mandate that egg breaking areas be washed and sanitized. The egg washer is drained, cleaned and refilled. The egg breaker is scrubbed and spray cleaned. The vat, which holds eggs as they come off the breaker, is pumped dry of product and then rinsed clean as is the sniff tank and strainer. Frequently substantial amounts of egg product remain in the vats, filters and pipes which are flushed onto the floor. After the machinery is cleansed it becomes necessary to wash down the floors to rinse away egg residuals, shells, and cleaning liquids. Normal production continues for another four-hour period when production is stopped by another clean-up procedure. At the end of the work day there is a final complete and intensive washdown which is similar to the noontime clean-up except that the breakers are scoured and steam cleaned manually. Vats, pipes and the pasteurizer are cleaned in place with high speed pumps that circulate detergents and washwater through closed loop systems. Figures 13 and 14 indicate the types of floor losses that might be avoided with careful in-plant management.

As previously mentioned, low quality eggs are segregated from breaking stock at the egg loading and candling operations and occasionally in the breaking operations. Human inedible liquid product can be sold to animal food producers once the shell fragments have been removed. In the plants surveyed three methods were used to separate liquid egg from its shell: 1) inclined shell auger, 2) centrifuging, and 3) commercial produced egg shell strainer.

SITE PREPARATION

Frequently, food plants use municipal water for the majority of their water and simultaneously supply its refrigeration plant with private

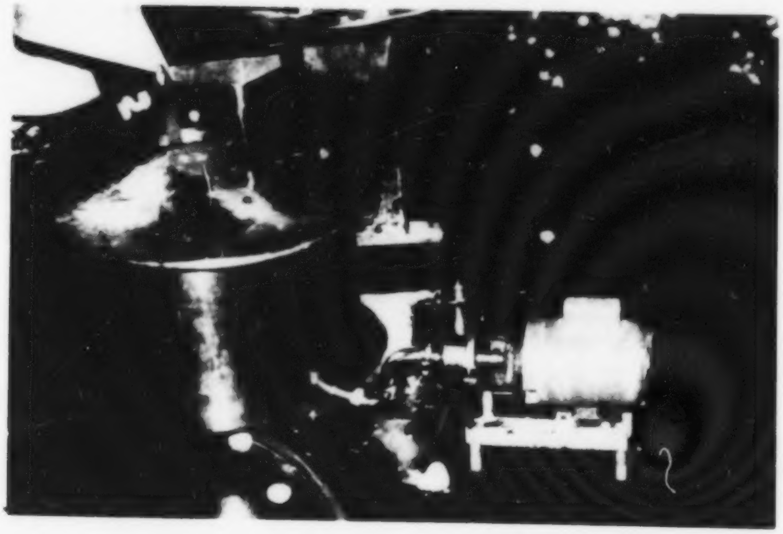


FIGURE 13. Example of floor egg liquid losses that can be avoided with in-plant management.

FIGURE 14. Example of floor egg liquid losses that can be avoided with in-plant management.

unmetered well water for cooling or wash-up water. Since undetected sources of water can easily dilute wastewater to be sampled and thereby indicate an erroneously low wastewater strength, weirs were used to supplement the metered water use to measure total flows in order to monitor a plant's total discharge. After locating all pipelines which carried wastes and the floor drains (except employee restrooms), excavation was made and a weir box, of specific dimensions, was fitted into position (Figure 15). The weir was then calibrated to be sure that handbook values of flow vs. height of weir overflow were identical to known flows through the weir (24).

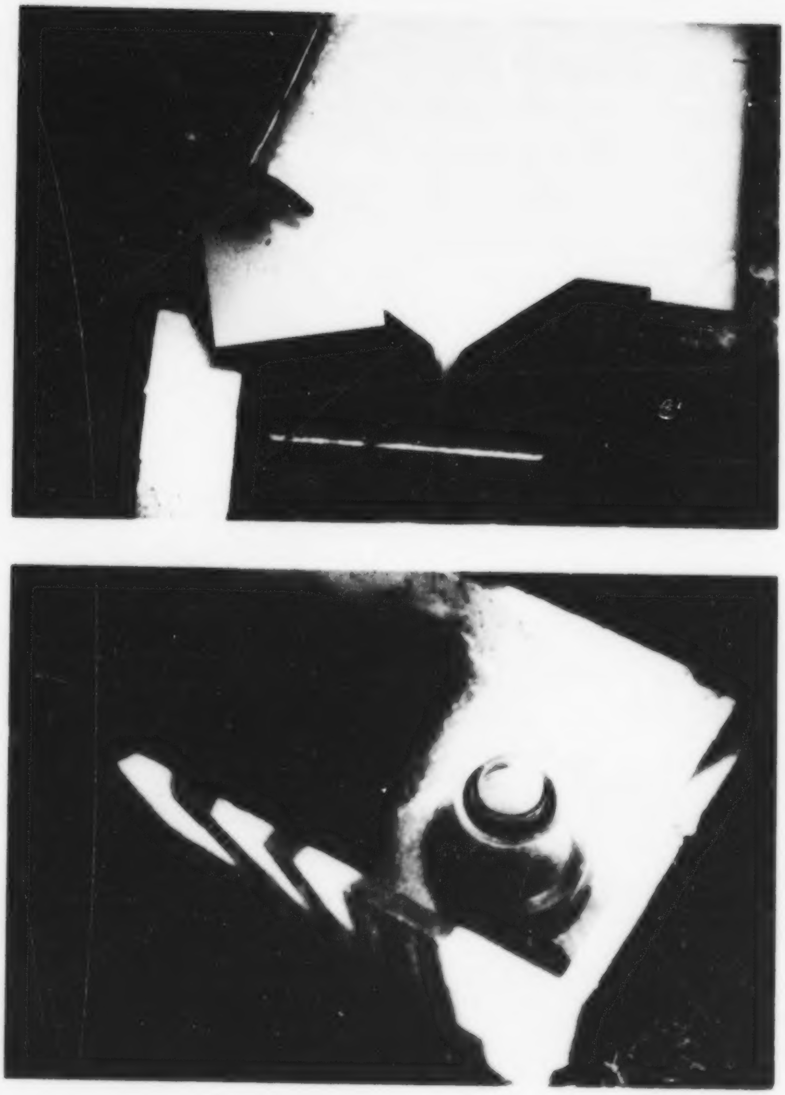


FIGURE 15. Example of flow measurement weir installed in Plants A, B, and C utilized for flow proportioned composite sample collection. All samples were stored in iced containers until the analysis could be conducted.

SECTION III

EGG BREAKING WASTE CHARACTERIZATION

WASTEWATER SAMPLING - BEFORE IN-PLANT MODIFICATIONS

External Measurements

Waste flows were measured at the point of discharge of each unit operation without alerting the normal plant operation. The goal was to gather base data at each plant in terms of water volumes, waste strength and chemical composition of materials wasted.

Wastewater samples collected at the outfall sampling stations were obtained by two methods. Grab samples were collected at half hour intervals and proportioned into a composite sample according to flow volumes during the same half hour period. An automatic sampler was also set to collect and combine nine equal sized samples per hour. All samples collected during the study were stored in iced-filled styrofoam coolers to minimize the biological degradation of the samples and chemical analyses were usually completed within 24 hours. Results of baseline flow characteristics and waste losses for Plants A and B are shown in Figures 16 and 17. This is the type of information that was developed for all five plants for at least two days and in some cases, 12 or more days.

The variability of water usage and BOD_5 losses confirms that the batch type operations of egg processing generate widely varying concentrated wastewaters. The water usage is greatly affected by minor clean-ups in the small facilities (Plant A in Figure 16). In larger facilities (Plant B with three breakers in Figure 17), the fluctuations in flow pattern is somewhat dampened by the continuous water usage of three breaking machines.

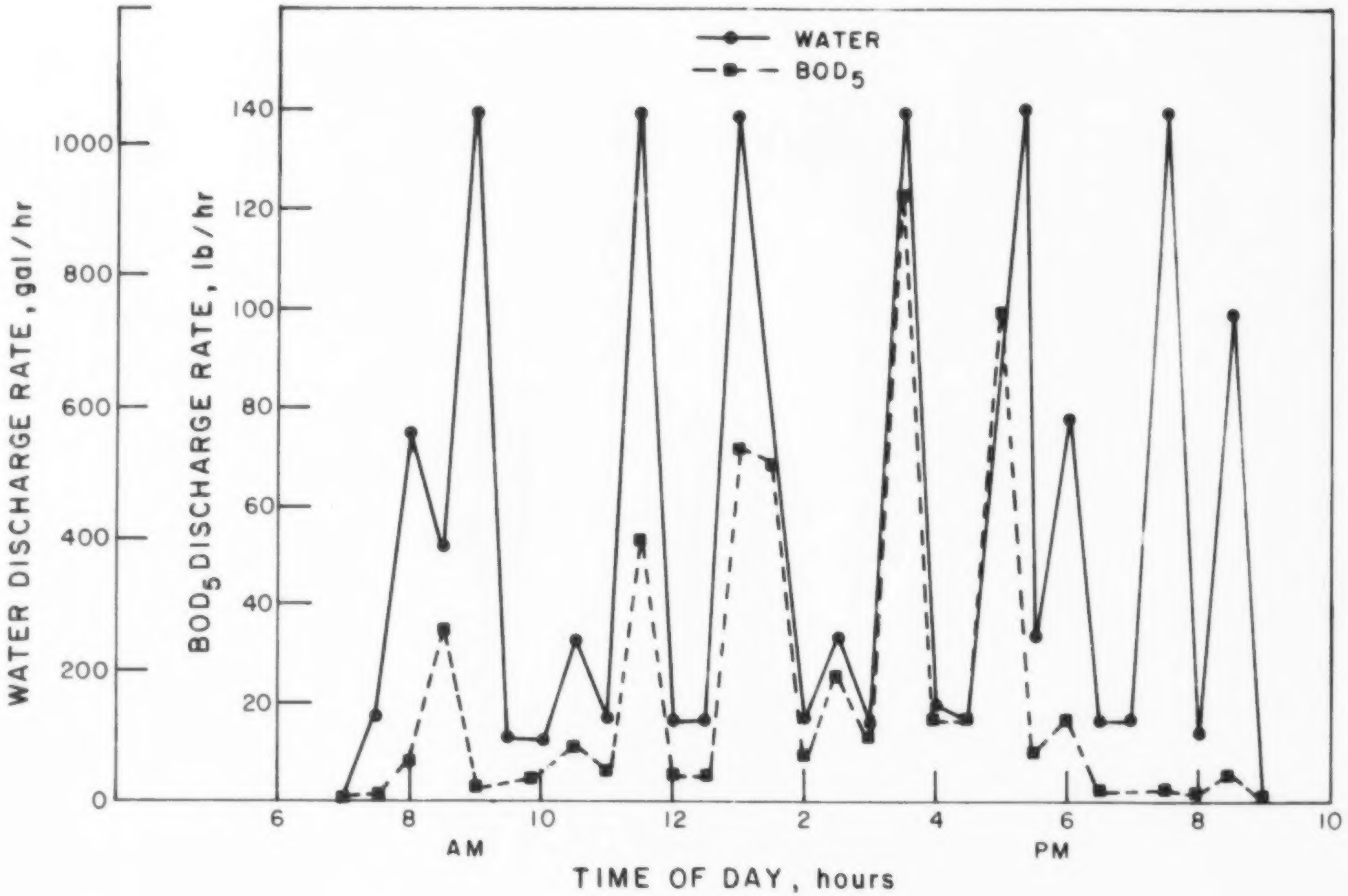


FIGURE 16. Example of the variation of water usage and organic losses (BOD_5) in Plant A before in-plant modifications.

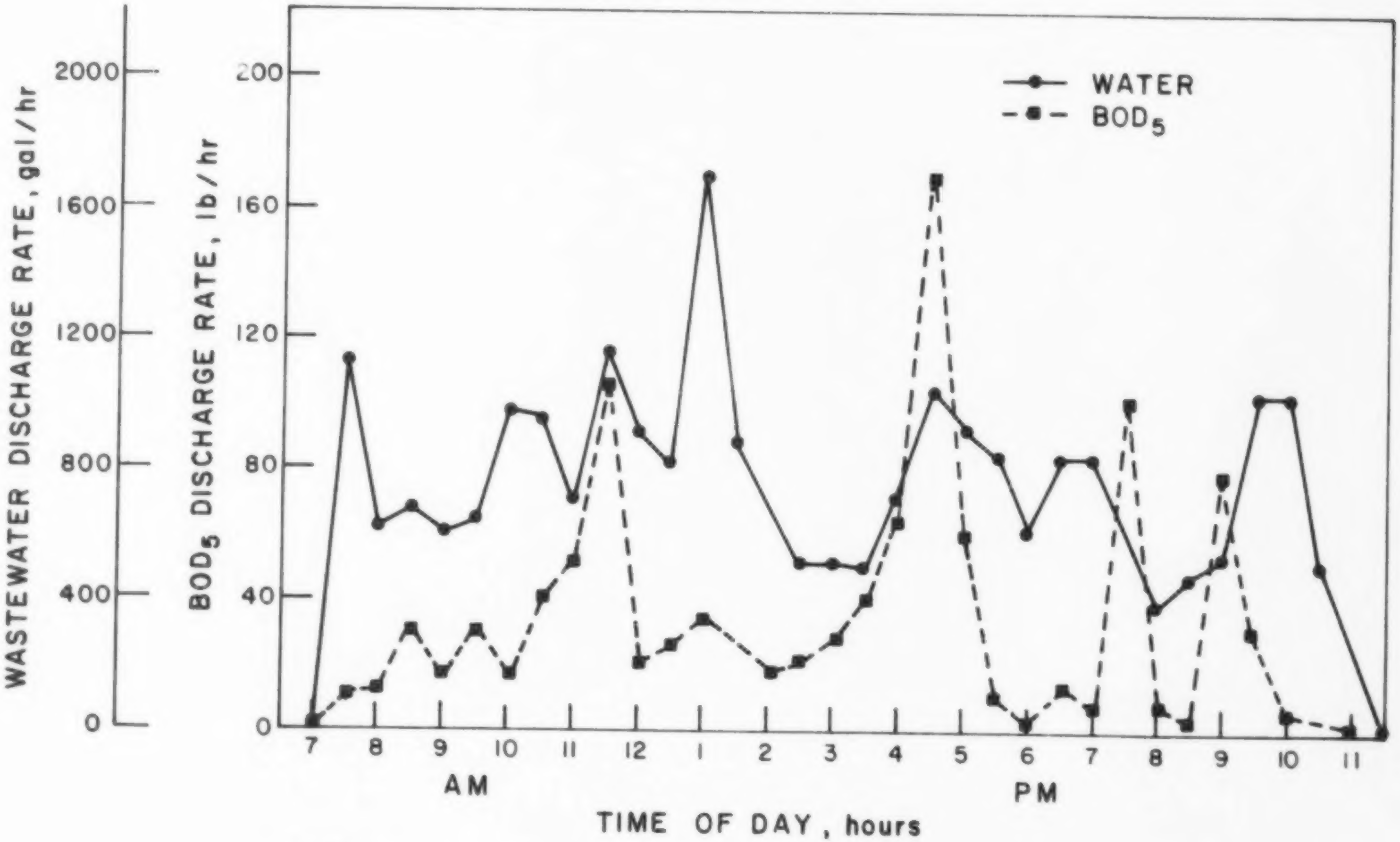


FIGURE 17. Example of water usage and organic losses (BOD_5) in Plant B before in-plant modifications.

Internal Measurements

In order to determine specific locations of waste loads in an egg processing plant, it was necessary to sample measurable losses of unit operations. In Plant A this included collecting weighted composite samples of the egg washer overflow and sump contents, continual overflow from the egg breaker and flushings of vats, tanks, strainers, piping and pasteurizer. Other sources of wastes include rejected inedible eggs from the washer and breaker operations that are not deposited in the proper receptacles, egg product dripping from the breaking machine, malfunctioning egg loading device on the egg washing machine, leaking pumps and piping connections and vat spillovers. All of the latter losses are examples of unmeasurable losses which constitute floor losses. In Plant B similar composite samples as noted above were obtained from both washers, three breakers, and a sump line which corresponds to losses of egg overflowing from the base of an inclined shell auger. All other losses were considered floor losses. There were no internal premodification measurements for Plant C during the 1972 study by Zall and Toleman (25).

Losses, before in-plant modifications, are shown in Figures 18 and 19. It can be seen that egg washers contribute at least 25% to a plant's total BOD loss, yet it constitutes only 5-10% of the plant's total water usage. Being such a highly concentrated unit loss suggests that it could be segregated from the plant's waste stream and disposed of separately. The large amount of wastes generated from "floor losses" would indicate that in-plant conservation methods should be effective in decreasing wastes.

In both plants it was noticed that egg breaking machines were operating with faulty flow valves and therefore using excessive amounts of water. This is evident from the fact that egg breakers utilized 25-33% of a plant's water consumption.

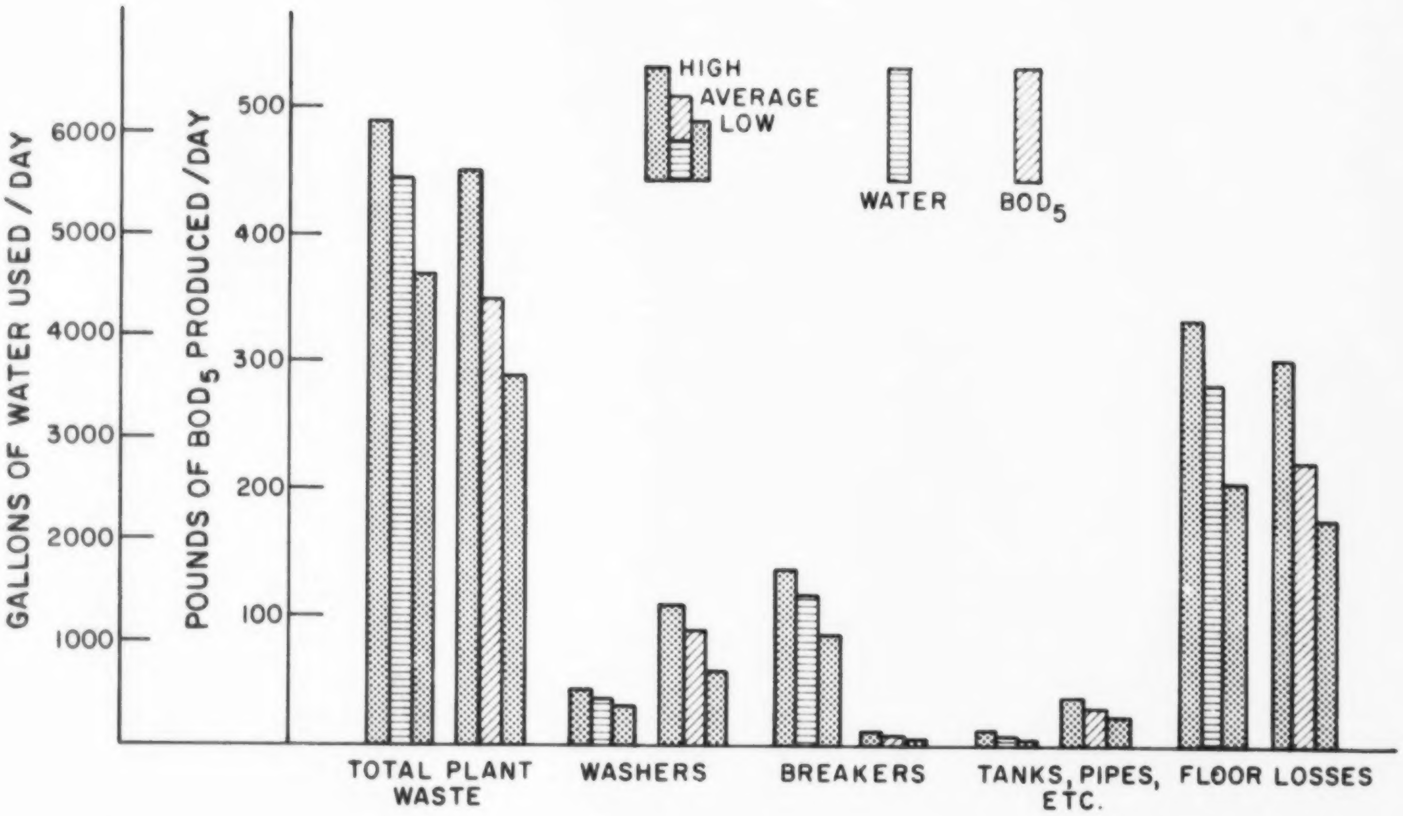


FIGURE 18. Unit process contribution of waste of egg breaking wastes before in-plant modification for waste reduction in Plant A.

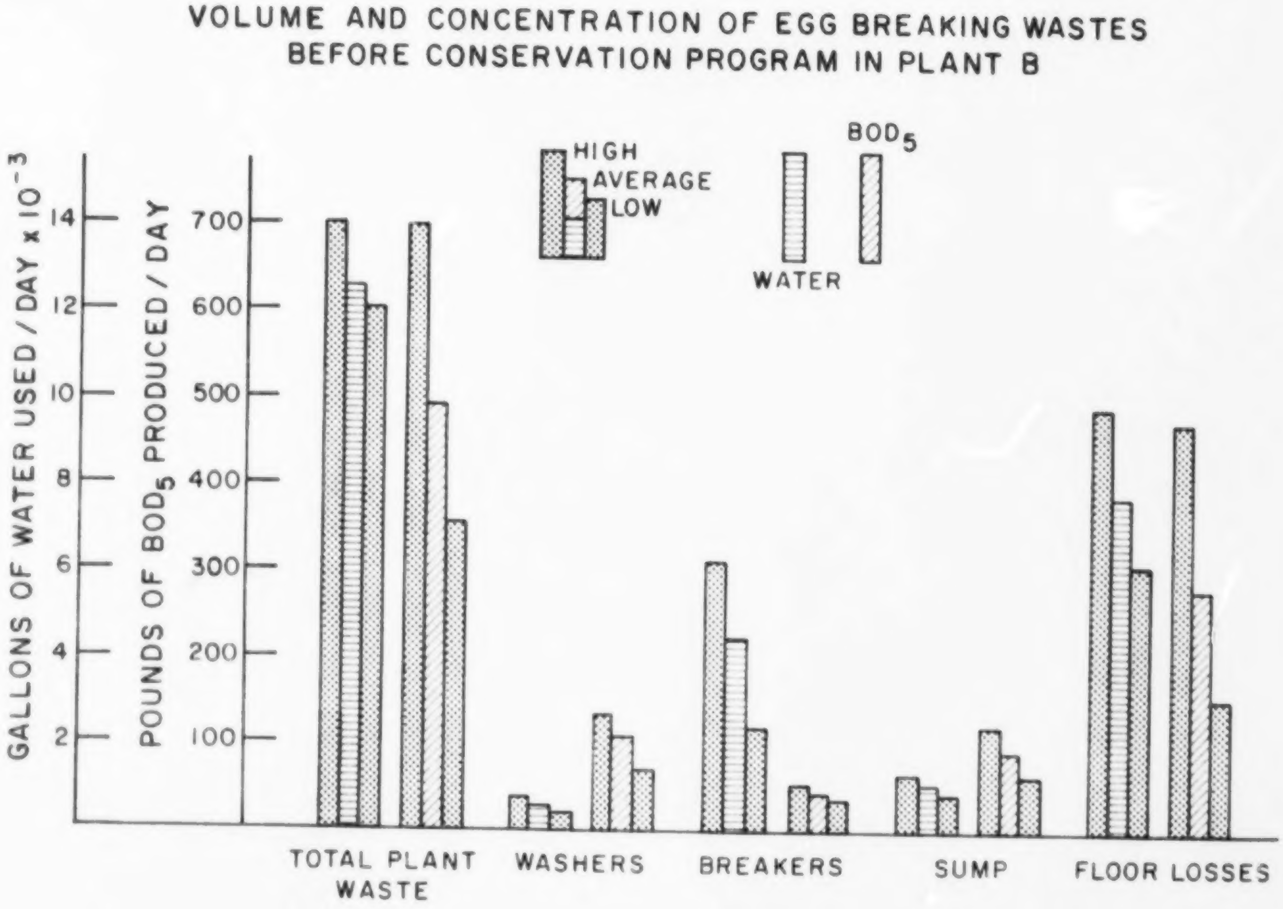


FIGURE 19. Unit process contribution of waste of egg breaking wastes before in-plant modification for waste reduction in Plant B.

In Plant A the total amount of egg product that was judged to be salvageable from pipes, pasteurizer strainer and vats, represents nearly 10 percent of Plant A's total BOD losses. In Plant B the unit loss designated as a sump loss is actually spillover of liquid egg from the base on an inclined auger carrying empty egg shells to a refuse truck. This waste source is easily converted to a salable by-product, and in plant B represented 20 percent of the total BOD.

The most significant loss in both plants was floor losses which contribute about 50% to a plant's total BOD loss. These unmeasurable losses result from malfunctioning equipment, leaking product pumps and piping, product spillover and plant clean-up. These losses for the most part indicate a need for more efficient working procedures and additional or modified equipment. These losses can be decreased through better on-job employee training and process modifications that stress improved product yields.

IN-PLANT MODIFICATIONS

After a plant's total losses and location of loss were determined, recommendations were made to alter the operating procedures to minimize waste production. Informing management of the weight of BOD_5 lost in their operation does not give them a clear understanding of their losses. A much more effective approach is to relate BOD or COD losses to the loss of egg product that can be easily translated to dollar losses. Although it is difficult to achieve, construction of a mass balance indicates the relationship of various losses to the final product. Enough data were obtained in this study to approximate a mass balance for plant A using the following approach.

The total input weight of incoming eggs to be broken was obtained from plant records. By subtracting the weight of the egg cartons, filler flats and pallet from the shipping weight of the eggs, the weight of the shelled eggs to be broken was obtained. Losses to the landfill were calculated assuming that the egg shell constitutes 11% of an egg's total weight and that 1.75% of an egg's liquid weight adheres to the shell after it is broken open and drained (26). The weight of inedible egg product, after being centrifuged to remove the shells, along with the weight of final product was also obtained from plant records. Losses of eggs to the sewer were calculated by knowing the volume of COD concentration of Plant A's wastewater, along with the COD and density of raw egg. The data shown in Figure 20 are an average of three separate days of sampling in which the total weight of material passing out of the plant checked within 5 percent of the total input. This type of data impressed management because it indicated that the egg loss represented greater than 8% of the plant's edible product output, and in this instance, represents a daily loss of about $435 (assuming a market value of $1.10 per kg [$0.50 per lb]). When it was noted that egg losses were substantial and resulted in decreased profit, plant managers were quick to understand the problem and were anxious to implement suggested in-plant modifications.

EFFECTS ON IN-PLANT MODIFICATIONS

Internal and External Measurements

Management at all three New York egg breaking plants agreed to implement some modifications suggested for waste control as given in Table 8. Although the degree to which the recommendations were adopted cannot be determined, the majority of the plants implemented those identified as 2, 3, 4, 6, 11 and 13 in Table 8. Based on previous data it was clear that eliminating the washer water, efficient recovery of discarded eggs (leakers, etc.) and recovery of the egg shell auger drippings would greatly reduce the effluent BOD. In essence each plant manager adopted the changes which he could implement quickly at a low cost without interrupting production. It was estimated that the cost of adoption

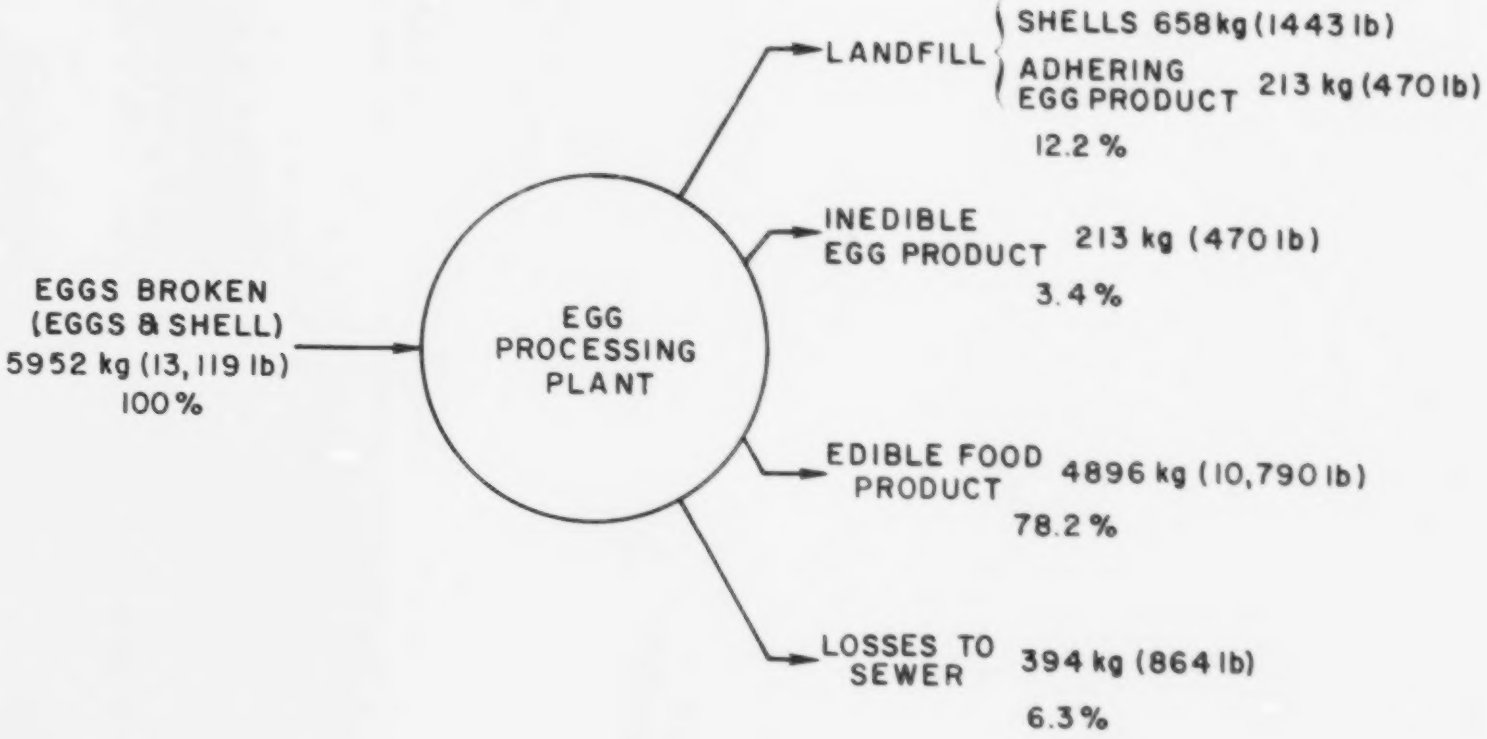

EGGS BROKEN
(EGGS & SHELL)
5952 kg (13,119 lb)
100%
EGG
PROCESSING
PLANT
LANDFILL
SHELLS 658kg (1443 lb)
ADHERING EGG PRODUCT 213 kg (470 lb)
12.2 %
INEDIBLE EGG PRODUCT 213 kg (470 lb)
3.4 %
EDIBLE FOOD PRODUCT 4896 kg (10,790 lb)
78.2 %
LOSSES TO SEWER 394 kg (864 lb)
6.3 %

FIGURE 20. Mass balance of egg materials in processing Plant A before waste control modification.

Table 8. RECOMMENDATIONS FOR MINIMIZING WASTE GENERATION IN EGG BREAKING FACILITIES

1. Minimize use of improper stacking of eggs in storage, or weak storage boxes.
2. Minimize number of times eggs handled and length of conveyor systems.
3. Efficient collection of discarded eggs.
4. Frequent adjustment of brushes in washers to minimize breakage.
5. Frequent inspection of egg breaking carrying trays to insure efficient collection.
6. Collection of shell attached albumen from conveyance system.
7. Eliminate storage vat spillovers.
8. Reduce lengths of product lines.
9. Minimize usage of water in plant clean-up.
10. Efficient removal of egg solids from storage units prior to rinsing.
11. Recovery of egg chalazaes and gelatinous egg solids from the egg strainer.
12. Recovery of initial flush of blend tanks and pasteurizer.
13. Segregate and recover or dispose on land the overflow and sump discharge from egg washing.

of the recommendations by Plant A and B did not exceed $300. It was also judged by the investigators that the recommendations that were adopted resulted in control of 80 to 90 percent of the waste material that would be controlled if all 13 recommendations had been used and strictly enforced.

Effluent samples were collected at Plant A by automatic sampling devices and also by proportioned composite samples. Internal measurements included composite samples of the overflow from the breaker, and rinsing from tanks, pipes and pasteurizer which were impossible to recover. The waste from the washer was not sampled because it was collected, stored, and land-filled weekly.

In Plant B effluent samples were collected using automatic and composite samples. Internal measurements consisted of composite samples from the breaker overflows, washers and the auger drippings (sump). This plant had made arrangements for land filling its washer water but had not actually segregated the wastes at the time of sampling, following in-plant modifications.

While at Plant C composite samples were obtained of the total plant effluent. Composite samples were taken of the auger overflow, breaker overflow, washer overflow and sump and the egg grading washer.

RESULTS OF SAMPLING BEFORE AND AFTER PLANT MODIFICATIONS

Comparison of the in-plant source of organics from common places was not successful in developing a method of predicting waste loads from various unit processes. Figure 21 illustrates the difference in waste loads developed in two washers and three egg breaking machines operating on the same type of egg quality input and handling the same amount of product. One washer produced about twice the amount of BOD_5. All three of the breakers produced about the same amount of BOD_5 per day but the water usage for one was about half that generated in the other two breakers.

Tables 9, 10, 11 are results of samples of the total wastewaters taken at the outfall pipes of three egg breaking plants. The data in these tables were derived from 6 to 15 composite samples made up of 20 to 30 half hour samples from each day. The wastewater characteristics in parentheses are values obtained from flow weighted composite samples whereas the remaining values are results of automatic Sigmamotor samples composited using time only. Comparison of the values obtained from these two sampling techniques indicated that the more accurate flow composited samples were always less than the samples composited according to time only. This is expected with highly variable wastes when

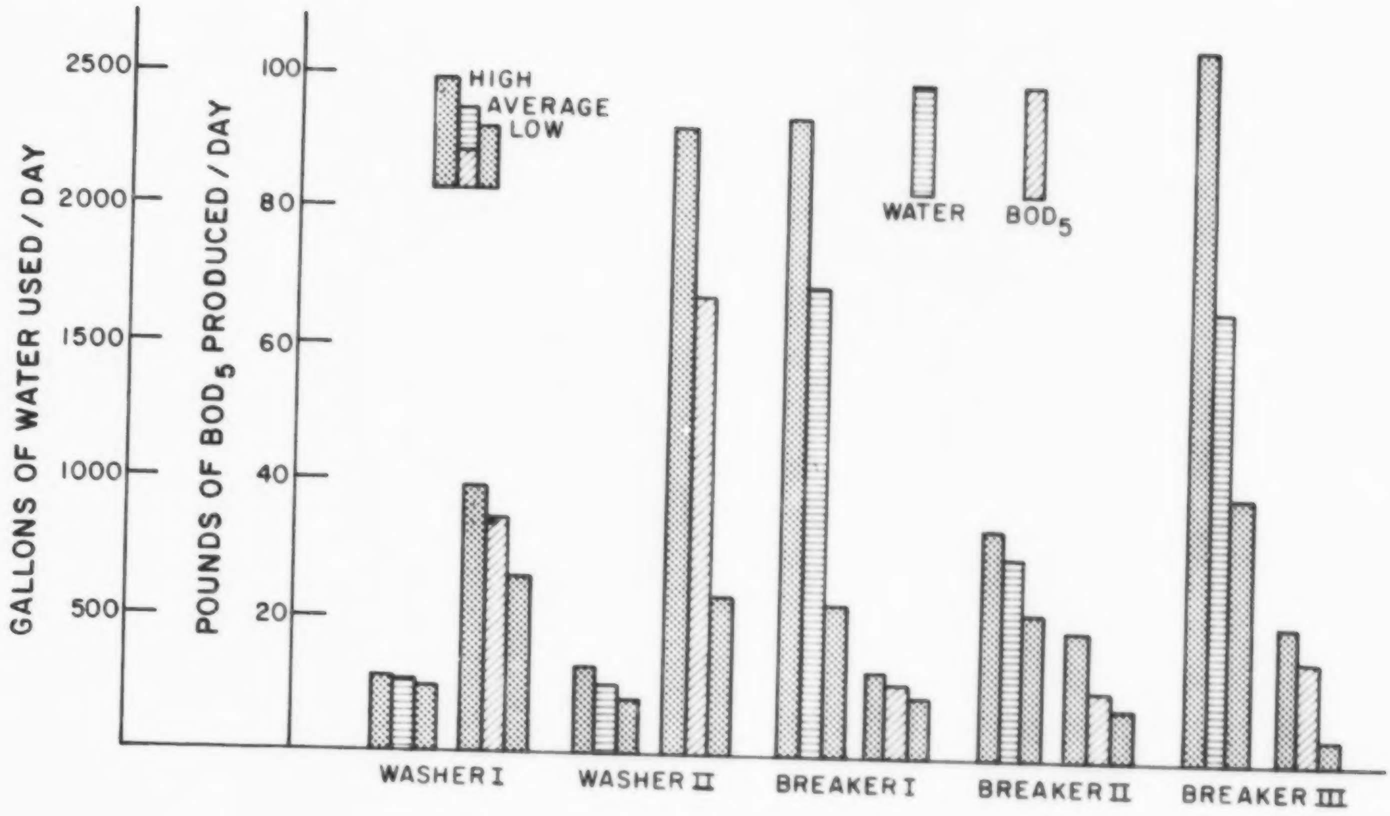


FIGURE 21. Waste loads generated from similar egg processing equipment in Plant B.

Table 9 . CHARACTERISTICS OF TOTAL WASTEWATERS FROM EGG BREAKING FROM PLANT A

Result	Total solids (mg/ℓ)	Suspended solids (mg/ℓ)	Total Kjeldahl nitrogen (mg/ℓ)	Ammonia nitrogen (mg/ℓ)	Total PO_4-P (mg/ℓ)	Total Alkalinity as $CaCO_3$ (mg/ℓ)
Initial unannounced samplings						
High	9,028[a] (5,911)[b]	2,655 (1,751)	737 (628)	5.9 (6.3)	24.4 (59.4)	526 (477)
Low	4,323 (5,382)	860 (1,250)	378 (462)	2.9 (3.3)	6.1 (9.8)	270 (283)
Average	6,676 (5,578)	1,758 (1,414)	558 (518)	4.4 (4.9)	15.3 (41.2)	398 (384)
No. of Determinations	12 (6)	6 (4)	6 (3)	8 (3)	8 (4)	5 (3)
Before plant modifications						
High	10,140	-	-	-	-	-
Low	4,907	-	-	-	-	-
Average	6,941	-	-	-	-	-
No. of Determinations	12					
After in-plant modifications						
High	5,744 (2,812)	1.385 (833)	461 (240)	7.7 (5.5)	22.2 (22.9)	456 (366)
Low	2,146 (1,396)	425 (180)	210 (84)	tr. (tr.)	12.7 (6.0)	208 (264)
Average	3,335 (2.237)	803 (519)	298 (178)	3.6 (2.9)	16.8 (11.8)	348 (312)
No. of Determination	14 (11)	16 (13)	16 (13)	12 (9)	14 (12)	9 (6)

[a] Time composited samples

[b] Flow composited samples

Table 10. CHARACTERISTICS OF TOTAL WASTEWATERS FROM EGG BREAKING FROM PLANT B

Result	Total solids (mg/ℓ)	Suspended solids (mg/ℓ)	Total Kjeldahl nitrogen (mg/ℓ)	Ammonia nitrogen (mg/ℓ)	Total PO_4-P (mg/ℓ)	Total Alkalinity as $CaCO_3$ (mg/ℓ)
Initial unannounced samplings						
High	4,847[a] (3,622)[b]	1,892 (899)	375 (283)	5.6 (5.7)	20.0 (17.1)	485 (402)
Low	3,792 (3,464)	829 (653)	312 (274)	4.7 (4.1)	16.2 (13.2)	366 (340)
Average	4,368 (3,557)	1,285 (776)	341 (278)	5.2 (5.0)	17.9 (15.1)	430 (385)
No. of Determinations	8 (8)	8 (7)	6 (6)	6 (6)	4 (4)	6 (4)
Before plant modifications						
High	6,875 (7,002)	2,121 (1,253)	517 (475)	21.2 (17.9)	27.3 (18.5)	574 (443)
Low	4,138 (4,452)	370 (330)	332 (405)	2.7 (2.8)	8.6 (9.1)	336 (343)
Average	5,347 (5,449)	1,062 (928)	397 (434)	8.1 (8.3)	17.9 (13.7)	430 (393)
No. of Determinations	12 (10)	10 (8)	8 (8)	8 (8)	6 (4)	8 (6)
After in-plant modifications						
High	4,411 (5,205)	865 (1,037)	338 (430)	2.83 (2.2)	11.6 (12.6)	429 (387)
Low	3,375 (3,177)	231 (190)	243 (232)	.46 (.8)	8.9 (7.8)	413 (354)
Average	4,006 (4,355)	539 (643)	295 (311)	1.54 (1.4)	10.0 (10.0)	419 (375)
No. of Determinations	9 (11)	16 (18)	8 (8)	6 (8)	6 (8)	8 (8)

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[a] Time composited samples

[b] Flow composited samples

Table 11. CHARACTERISTICS OF TOTAL WASTEWATER FROM EGG BREAKING FROM PLANT C

Result	Total solids (mg/ℓ)	Suspended solids (mg/ℓ)	Total Kjeldahl nitrogen (mg/ℓ)	Ammonia nitrogen (mg/ℓ)	Total PO_4-P (mg/ℓ)	Total Alkalinity as $CaCO_3$ (mg/ℓ)
Before plant modifications						
No Data Available						
After in-plant modifications						
High	5,952	1,593	413	3.7	55	1,165
Low	3,727	75	225	0	35.9	760
Average	4,514	753	302	2.0	42.8	1,009
No. of Determinations	12	12	8	8	8	8

large and highly contaminated flows occur over short time periods. In most cases the difference between values obtained using the different methods was less than 20 percent even for the high and low values. The difference between the two averages was usually less than 10 percent. Thus it may be concluded that time composited samples are adequate for obtaining average concentrations in this industry.

Notable reductions in wastewater pollutant concentrations are indicated in this data. However, reduction in concentrations does not indicate the quantity of material actually removed from the wastewaters. The mass balance data give a much clearer idea of the effectiveness of in-plant control (Table 12). On the average, 73 percent of organics lost to the sewer was diverted by in-plant modifications. As can be seen in Table 12, the bulk of the captured material ended up in animal food. Thus this demonstrated that a pollution problem was converted into a salable product.

Tables 13 and 14 show BOD_5 and COD values of the wastewater at Plants A and B. The oxygen demand of both effluents are reduced by conservation measures. In plant A, the BOD_5 was largely reduced by segregating the washer water and landfilling it with the wasted egg shells. In plant B, the BOD_5 was reduced by improved floor management. The washers at this plant were not segregated and landfilled at the time of post modification sampling, thus the oxygen demand of the wastewater can be reduced below the values of Table 14. The overall average ratio of BOD_5/COD for all samples was 0.58. This compares well to the value of 0.66 use as an assumption in the study by Kaufman et al. (22).

Expressing waste loads in lbs per dozen eggs as opposed to strictly BOD_5 or COD concentration takes into account the volume of water used in processing and the amount of production. A waste stream could have a BOD_5 of 3,000 mg/ℓ before in-plant modifications. This seems to indicate no reduction in waste. However, if the volume of wastewater after

Table 12. COMPARISON OF WASTEWATER MASS BALANCES OBTAINED FOR EGG BREAKING OPERATION IN PLANT A BEFORE AND AFTER MODIFICATION FOR WASTE CONTROL

Sample Day	Difference between input and output, % input	Fate of input, Fraction of total throughput, %			
		Shells and adhering albumen	Animal food	Edible food	Loss to sewer
Before modification					
1	-6.8[a]	12.5	4.2	76.5	7.3
2	-3.5	12.1	2.2	81.6	3.7
3	-5.7	11.9	3.7	76.5	7.9
Average	-5.3	12.2	3.4	78.2	6.3
After modification[b]					
1	-5.2	12.0	13.6	72.5	2.3
2	+3.0	12.5	4.3	78.5	1.8
3	-4.0	12.1	5.7	81.0	1.1
Average	-2.0	12.2	7.9	77.3	1.7

[a] Negative value indicates calculated more output than input

[b] Egg washing volume not included after modifications since it was taken to landfill.

Table 13. BIOCHEMICAL AND CHEMICAL OXYGEN DEMANDS OF TOTAL EGG BREAKING WASTES FROM PLANT A

Result	BOD_5	COD	BOD_5/COD ratio
Initial unannounced sampling			
High	7,987[a] (7,106)[b]	17,901 (14,349)	
Low	4,350) (5,887)	5,902 (7,840)	
Average	6,168 (6,407)	11,902 (10,536)	.518 (.608)
No. of Determinations	14 (16)	6 (14)	
Before plant modification			
High	11,475	14,800	
Low	5,267	8,964	
Average	7,279	10,832	.672
No. of Determinations	10	6	
After in-plant modification			
High	6,150 (2,595)	9,834 (4,390)	
Low	1,132 (589)	2,523 (1,595)	
Average	2,992 (1,654)	5,005 (3,202)	.598 (.516)
No. of Determinations	17 (20)	19 (22)	

[a] Time composited samples

[b] Flow composited samples

Table 14. BIOCHEMICAL AND CHEMICAL OXYGEN DEMANDS OF TOTAL EGG BREAKING WASTES FROM PLANT B

Result	BOD_5	COD	BOD_5/COD ratio
Initial unannounced sampling			
High	4,443[a]	7,084	
	(3,202)[b]	(5,482)	
Low	3,364	5,382	
	(2,782)	(4,884)	
Average	3,961	6,416	
	(2,998)	(5,200)	(.576)
No. of Determinations	4	5	
Before plant modification			
High	6,684	11,483	
	(5,939)	(9,701)	
Low	3,054	5,821	
	(3,815)	(6,462)	
Average	4,563	7,832	.588
	(4,661)	(7,759)	(.601)
No. of Determinations	8	20	
After plant modification			
High	3,443	6,862	
	(4,793)	(9,051)	
Low	2,949	4,566	
	(2,580)	(4,025)	
Average	3,169	6,050	.524
	(3,661)	(6,868)	(.533)
No. of Determinations	8	20	

[a] Time composited samples

[b] Flow composited samples

modifications is reduced by 50%, then the lbs of waste is reduced by 50% when BOD_5 concentrations were equal. The weight of waste alone also is not a true indicator of losses. A plant could have lost 100 lbs of BOD before and after modifications, which again could easily be mistaken as an indication of no reduction of product losses. If in fact this plant processed twice as many eggs per day during the post modification period, then the loss per dozen eggs processed will have been reduced by 50%.

Sewer Losses Per Unit Product

The most meaningful expression to compare product loss to the sewer to another production facility would be to relate each amount of production to common pollutants. Unfortunately, the most common unit of production in the egg industry is the case or dozen. This measure is not as useful as total weight of production. The weight relationship for eggs varies from 0.94 lbs per dozen for small eggs to 1.87 lbs per dozen for larger eggs. According to data in Part I of this report, the shell composes 11 percent of the total weight of the egg. Thus the weight of the liquid portion of eggs varies from 0.84 to 1.66 lbs per dozen for various sizes. Industry uses a rule of thumb that 83 percent of the total weight of the egg ends up as egg product. The data in Table 15 show the relation between numbers of eggs handled, weight of the eggs, and fraction of the total weight which became salable product. During four of the five days the eggs weighed about 1.5 lbs per dozen and about 1.2 lbs per dozen were recovered as processed egg material. This amounted to recovery of about 80 percent of the total weight of eggs broken in liquid egg product, or slightly less than the rule of thumb. In the following discussion, losses expressed on a weight loss per dozen eggs broken will be converted to weight using the average 1.21 lbs of egg recovered per dozen eggs broken.

Table 15. WEIGHT OF EGGS PROCESSED AND FRACTION OF EGG MATERIAL RECOVERED IN THE PRODUCT CALCULATED FROM MASS BALANCE DATA FOR PLANT A

Sample day	Input lbs eggs and shells per dozen	lb liquid egg produced per dozen eggs broken	Final processed egg % initial
Before modification			
1	1.47	1.21	82
2	1.52	1.21	80
3	1.47	1.18	80
After modification			
1	1.50	1.20	80
2	1.73	1.35	78

Tables 16-19 represent volume of water and BOD losses for five various sized egg processing plants. Plant A has accomplished greater than 50% reduction in lbs BOD/dozen. Plant B has similar results even though the two egg washers in the plant were not segregated from the waste stream and landfilled. Plant C has accomplished a 75% reduction by improved floor management without landfilling washer water. Plant D made very little effort to recover egg product from the inclined auger, egg sniff tanks and strainers and thus the loss of product is excessively high. Plant E made sincere efforts to capture auger drippings, residual egg in tanks and pipes during cleanup, recover strainer solids, and also scrape egg solids off the floor which had resulted from drippings or spillover. These efforts are reflected by reduced losses.

The maximum range of water and product loss for all plants was 0.43 to 1.41 gal. per dozen and 0.0048 to 0.0478 lb BOD_5 per dozen, respectively.

Table 16. VOLUME AND WEIGHT OF EGG BREAKING WASTES GENERATED PER UNIT EGGS PROCESSED IN PLANT A

	Production Rate	Volume Wastewater		Weight Egg Lost	
Result	doz/day	gals/day	gals/doz	BOD_5(lb) per doz	BOD_5(lb) per lb liquid egg
Before announced sampling					
High	10,260	4,710	.459	.0306 (.0341)[a]	.037 (.041)
Low	9,330	4,010	.430	.0155 (.0194)	.0188 (.024)
Average	9,795	4,360	.445	.0230 (.026)	.0278 (.0314)
No. of Determinations	4			18	18
Before plant modifications					
High	9,330	6,133	.711	.0478	.0577
Low	7,290	4,338	.500	.0261	.0316
Average	8,385	5,235	.627	.0373	.0451
No. of Determinations	4			18	18
After in-plant modifications					
High	8,790	5,846	.952	.0218 (.0193)	.0204 (.0234)
Low	4,620	3,615	.452	.0048 (.0077)	.0058 (.0093)
Average	6,945	4,576	.689	.0150 (.01000)	.0181 (.012)
No. of Determinations	6			36	36

[a] Samples composited according to flow, all others composited according to time

Table 17. VOLUME AND WEIGHT OF EGG BREAKING WASTES GENERATED PER UNIT EGGS PROCESSED IN PLANT B

	Production Rate	Volume Wastewater		Weight Egg Lost	
Result	doz/day	gals/day	gals/doz	BOD_5(lb) per doz	BOD_5 (lb) per lb liquid egg
Before announced sampling					
High	18,930	15,970	1.219	.0414 (.0323)[a]	.050 (.039)
Low	13,080	15,050	.844	.0262 (.0212)	.0317 (.0256)
Average	16,050	15,653	.998	.0329 (.025)	.0398 (.0302)
No. of Determinations	3			18	18
Before plant modifications					
High	17,370	13,990	.878	.0397 (.0371)	.098 (.0448)
Low	15,930	12,010	.712	.0220 (.0263)	.0266 (.0318)
Average	16,680	12,825	.770	.0287 (.0304)	.0347 (.0368)
No. of Determinations	6			34	34
After in-plant modifications					
High	20,052	11,220	.768	.0199 (.0203)	.024 (.0246)
Low	10,110	7,770	.510	.0125 (.0165)	.0151 (.2001)
Average	15,719	9,737	.646	.0171 (.0188)	.0207 (.0228)
No. of Determinations	3			18	18

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[a] Samples composited according to flow, all others composited according to time.

Table 18. VOLUME AND WEIGHT OF EGG BREAKING WASTES GENERATED PER UNIT EGGS PROCESSED IN PLANT C

	Production Rate	Volume Wastewater		Weight egg lost	
				BOD_5 (lb) per doz	BOD_5 (lb) per lb liquid egg
Result	doz/day	gals/day	gals/doz		
Before announced sampling[a]					
	3,750	3,597	.959	.0266	.0322
After in-plant modifications					
High	6,330	1,845	.319	.0078	.0095
Low	4,050	1,139	.209	.0051	.0062
Average	5,040	1,382	.274	.0069	.0084

[a] Results taken from one day of sampling in 1972 (2).

Table 19. VOLUME AND WEIGHT OF EGG BREAKING WASTES GENERATED PER UNIT EGGS PROCESSED IN PLANTS D AND E

	Production Rate	Volume Wastewater		Weight Egg Lost	
				BOD$_5$ (lb) per doz	BOD$_5$(lb) per lb
Result	doz/day	gals/day	gals/doz		liquid egg
Plant D - Before modifications					
High	112,470	126,400	1.41	.0270	.0327
Low	82,800	103,900	1.08	.0252	.0305
Average	93,360	115,000	1.23	.261	.0316
No. of Determinations	2			16	16
Plant E - After modifications					
High	70,400	64,150	1.25	.0277	.0335
Low	36,000	37,000	1.03	.0163	.0197
Average	46,670	52,800	1.13	.0201	.0243
No. of Determinations	2			16	16

A summary of the average losses is given in Table 20. The measured BOD_5 losses have been converted to liquid egg losses using the average relationship between BOD and COD (0.58) and COD and whole egg liquid (0.47 ref. 24). For the four plants sampled without modifications for waste control, 12 percent of the amount of liquid egg processed goes to the sewer. In other words, more than one egg out of every dozen goes to the sewer in about 0.9 gallons of water. On the other hand, in plants where waste conservation and in-plant waste management was utilized, the average loss was reduced to 6.5 percent of processed product with a low of 3.1 percent lost. The average water volume generated in modified facilities was 24 percent less than that in the unmodified facilities. Figure 22 summarizes the average water and BOD loss measured in all facilities in this study.

The egg losses are more than those reported in three plants in Holland (27). See Table 21. The three Dutch plants surveyed include one facility that had no washing and one that washed both eggs and the plastic trays in which the eggs were delivered. The water use of 0.49 to 1.56 gallons per dozen eggs was the same as reported here, but the amount of product lost varied from a low of 0.5 to 4.2 percent of processed egg.

In another survey of plant practices (22) in the U.S. , water losses from 21 plants and organic losses from 9 plants were estimated by the plants' personnel (Table 22). The water use ranged from 0.485 gallons per dozen eggs processed to 3.27 gallons per dozen eggs with an average of 1.49 gallons per dozen eggs. The range of wastewater generated agrees with that found here and the Dutch study. However, the average appears to be high. It should be noted that some lower waste generation rates were discarded as being in error in the U.S. study (22).

The product loss reported for the nine plants surveyed in the U.S. study (22) agrees with the detailed study presented here. The product loss ranged from a low of 4 percent to 25 percent of processed egg liquid,

Table 20. SUMMARY AVERAGE UNIT PRODUCTION WASTEWATER VOLUME AND ORGANICS GENERATED IN EGG BREAKING FACILITIES

	Plant A	Plant B	Plant C	Plant D	Plant E	Avg.
Before modifications						
Volume wastewater (gal./doz)	0.536	0.884	0.959	1.23	-	0.90
Weight egg loss (BOD_5(lb)/lb liquid eggs)[a]	0.0380	0.0345	0.0322	0.0316	-	0.0341
(lb (wt)/lb liquid egg processed)[b]	0.14	0.126	0.118	0.116	-	0.125
After modifications						
Volume wastewater (gal./doz)	0.689	0.646	0.279	-	1.13	0.686
Weight egg loss (BOD_5(lb)/lb liquid eggs)[a]	0.0120	0.0228	0.0084	-	0.0243	0.0169
(lb (wt)/lb liquid egg processed)[b]	0.044	0.083	0.031	-	0.100	0.064

[a] Calculated by assuming that the weight of liquid egg obtained from one dozen eggs was 1.21 lbs.

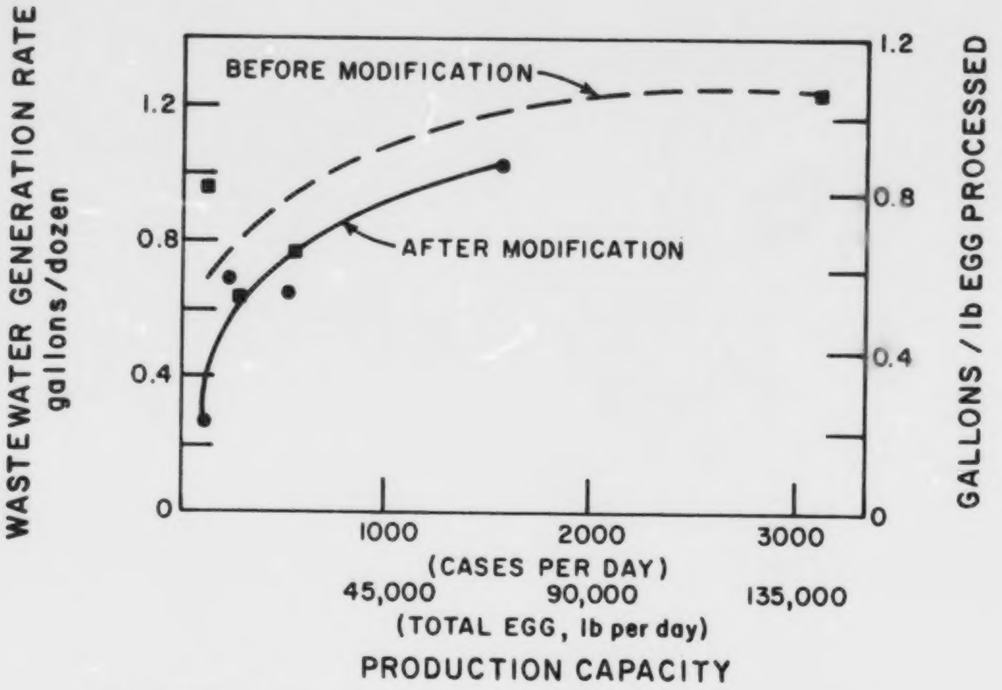
[b] Calculated as follows:

$$\frac{\text{lb BOD}_5\text{ lost}}{\text{lb egg liquid processed}} \times \frac{\text{lb COD}}{\text{0.58 lb BOD}} \times \frac{\text{lb egg liquid}}{\text{0.47 lb COD}} = \frac{\text{egg liquid lost}}{\text{lb egg produced}}$$

Table 21. WASTEWATER GENERATION INFORMATION FROM THREE EGG BREAKING FACILITIES IN NETHERLANDS (27)

Plant	Plant activities		Volume wastewater generated per unit processed egg			Organics lost to sewer per unit processed egg		
	Egg Wash	Egg & Tray Wash	$\frac{m^3 \text{ water}}{1000 \text{ Kg}}$	$\frac{\text{gal water}^a}{\text{doz}}$	$\frac{\text{gal water}}{\text{lb egg}}$	$\frac{\text{Kg BOD}_5}{1000 \text{ Kg}}$	$\frac{\text{lb BOD}_5}{\text{doz}}$	% Lost[a]
A	yes	yes	3.8	0.49	0.45	14	0.015	2.8
B	yes	no	12.0	1.56	1.43	21	0.023	4.2
C	no	no	8.0	1.04	0.97	2.4	0.0026	0.5

[a] Calculated using average weight relationships noted in text.



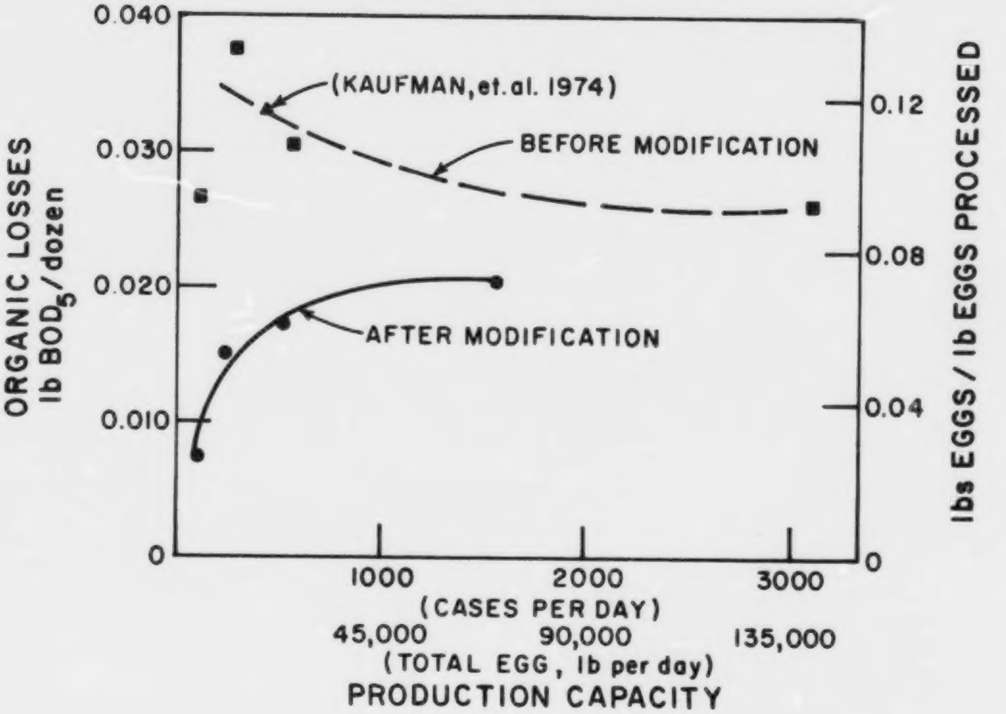


FIGURE 22. Summary of the average organic and water volume losses before and after plant modification for waste control.

Table 22. SURVEY OF WASTEWATER CONTROL AT U.S. EGG PRODUCT PLANTS (22)

	Range	Average
Volume wastewater (21 plants), gal per lb of pasteurized product	0.4 to 2.7[a]	1.23
Organic waste load, BOD_5		
Concentration, mg/l (9 plants)	1700-6000	3900
lbs per 1000 lb pasteurized product (7 plants)	11- 70	33
lbs per day for plant pasteurizing 20,000 lb egg		660

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[a] Some values lower than 0.4 were reported by plant manager but discarded by the authors and not used in the average.

and averaged 12.1 percent of the processed material. As was noted earlier this is the overall average value for product loss as measured in the four plants sampled during this study that had no modifications for waste control.

It is interesting to note that the relative magnitude of a waste source which was not adopted by management in the study was reported by Kaufman et al. (22). Start and stop losses in a pasteurizer in a 20,000 lb per day plant accounted for a product loss amounting to 5 percent of processed material, or nearly half the average total losses. Although recovery or reduction of this waste material may be difficult to achieve and was not used in this study, emphasis on this possibility would lead to even more effective waste management than was demonstrated in this study.

The water usage consumption was reduced mainly by correcting faulty water valves on the egg breaking machines and placing spray nozzles on all water hoses. Water usage has been observed to increase with the size of breaking plants and is due in part to the greater diameter of water hoses used throughout the larger plants during clean-up.

It is difficult for plant operators to determine the effectiveness of in-plant management methods because of the difficulty of obtaining information on the wastewater characteristics. An attempt was made to relate the major water quality parameters to the simple measurement of total solids for two plants. The agreement among data points shown in Figure 23 was almost exactly the same for both facilities supporting the assumption that the main source of pollution is from egg material. Thus, the plant operator could obtain approximate concentrations of pollutants in his effluent by correlating total solids to other parameters.

Another major concept supported by the relationship shown in Figure 23 is that the relative composition does not change after in-plant

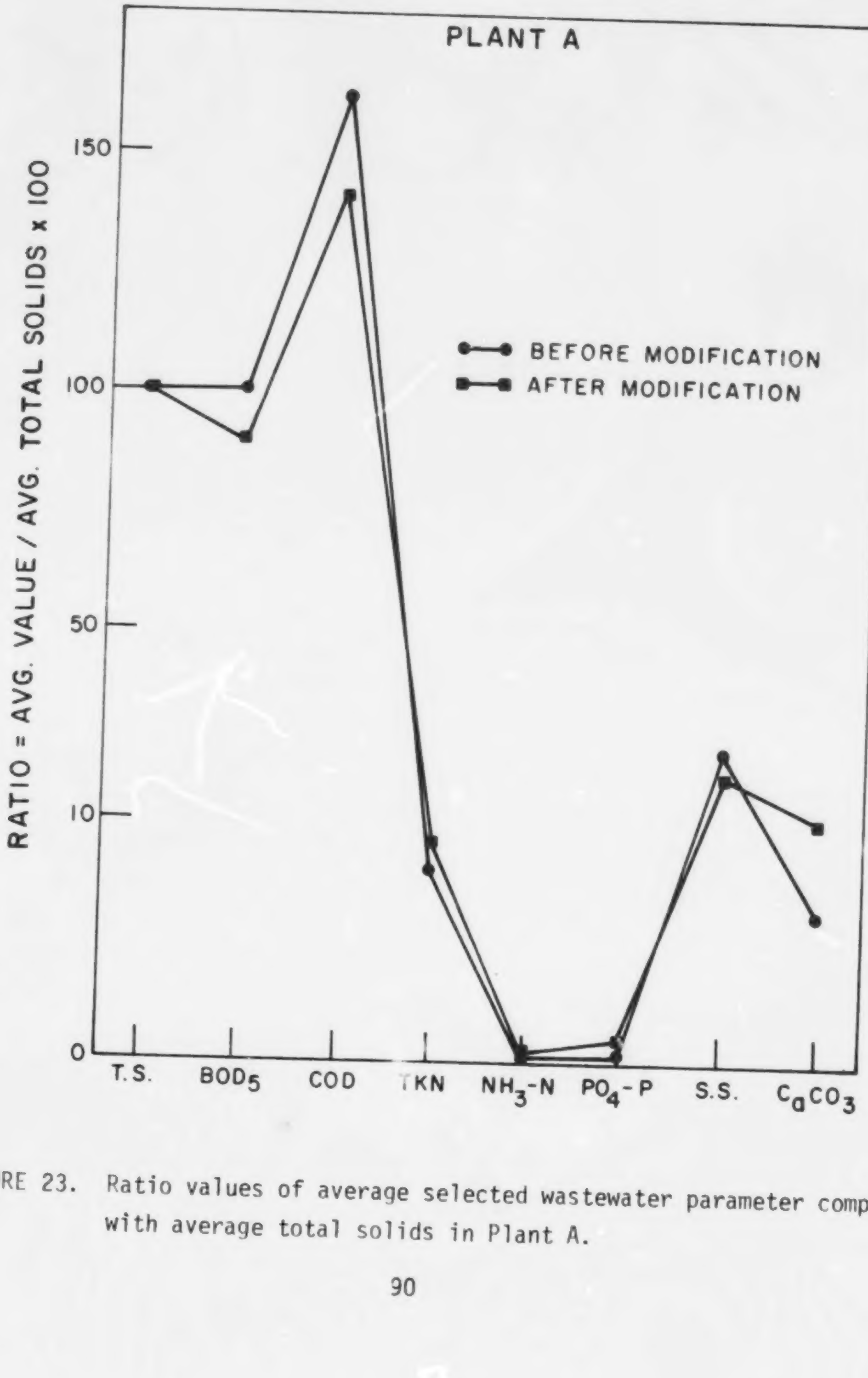

FIGURE 23. Ratio values of average selected wastewater parameter compared with average total solids in Plant A.

modifications are adopted. In other words, the concentrations and total weight of pollutants may change but this does not greatly increase the COD and decrease other parameters such as the nitrogen concentrations. This is an important conclusion in regards to development of treatability data for wastewater from facilities with and without in-plant management. It would appear that the treatability results would be applicable to plants with or without in-plant waste conservation.

SECTION IV

DISCUSSION AND OBSERVATIONS

EFFECTIVENESS OF WASTE MANAGEMENT RECOMMENDATIONS

The following recommendations were suggested to plant operators to help reduce waste and at the same time increase profits. All of the following suggestions were not followed by each plant, but enough were adopted to indicate the anticipated impact on waste reduction.

1) Egg shell breakage can result from shipping of improperly stacked cases. Therefore, it would be advantageous to note the condition of incoming eggs to inform distributors of mishandling. Some egg producers may ship excessive numbers of "leakers" which when loaded onto the washer are broken open and the contents emptied into the wash water. If a plant operator finds that one of his suppliers is consistently providing an abnormal amount of "leakers", it would be to the operator's benefit to try to locate a new distributor as opposed to suffering decreased yields, increased product loss and increased cost due to pollution control.

2) Egg losses can be reduced by loading eggs directly into egg washers as opposed to loading eggs onto conveyor belt systems which in turn carry eggs to the washer. This was adopted by one plant and resulted in a more efficient production line and apparently decreased egg losses, but quantitative data were not available.

3) Personnel who load eggs onto the washer oversee the candling operation and breaking machine operators are expected to remove and discard inedible eggs, whether they be "leakers," "bloods," or spoiled. A wide mouthed funnel or inclined trough placed next to each of these personnel, guide rejected eggs into a receptable without causing floor losses.

4) The vertical motion of the egg washer brushes, particularly when they are out of adjustment, can penetrate egg shell openings and cause eggs to be broken. The brushes can be readily readjusted when they are detected as operating incorrectly. A relationship such as that shown in

Figure 24, relating a quantitative measurement of apparent optical density to waste concentration, would enable any operator to note malfunctions in equipment or abnormal egg conditions causing a high rate of soluble egg to appear in the washer water. A more sophisticated approach would be to have plants install turbidity detectors.

5) Regular inspections of breaking machines should be carried out to be sure that trays which catch eggs released from the breaker cups do retain eggs on the tray; trays are properly overlapped; hoses carrying product from the breaker to collection vats are securely fastened; and the water control valve for the cup sprays is not opened to the point that water is being used at a rate greater than 7.6 ℓ/min (2 gal./min).

6) The usual means of transferring egg shells from the breaker to a refuse truck was by use of an auger. By tilting the auger at 30° to 45° the adhering albumen can be separated from the shell and can be collected.

7) Liquid level indicators could be placed in vats which hold egg product from the breaker, sniff tanks and blend tanks to prevent spillovers. Without the use of probes it is up to a plant employee to manually turn pumps on and off and at the same time perform other duties. The latter technique is unsatisfactory and has been observed to result in spillovers of product at least once in every breaking day.

8) Losses of egg product can be reduced by keeping product pipe lines as short as possible, pitching the pipes so that they drain to the product's final destination, and eliminating unnecessary equipment such as blend tanks when egg additives are not used.

9) Plant clean-up operations offer numerous opportunities for product recovery. During the two major clean-up operations in the egg breaking day, it is possible to add water to the vat following the breaker and pump it to the sniff tank. This enables egg to be flushed out of the product lines. When the product entering the sniff tank is obviously low in egg solids, the flow is diverted to the floor.

10) The sniff tank is completely drained at each major clean-up period; however, egg solids will still remain adhered to the tank's sides and bottom. By tilting the sniff tank on its side, the solids can be removed with a hand squeegee and pasteurized in future batches.

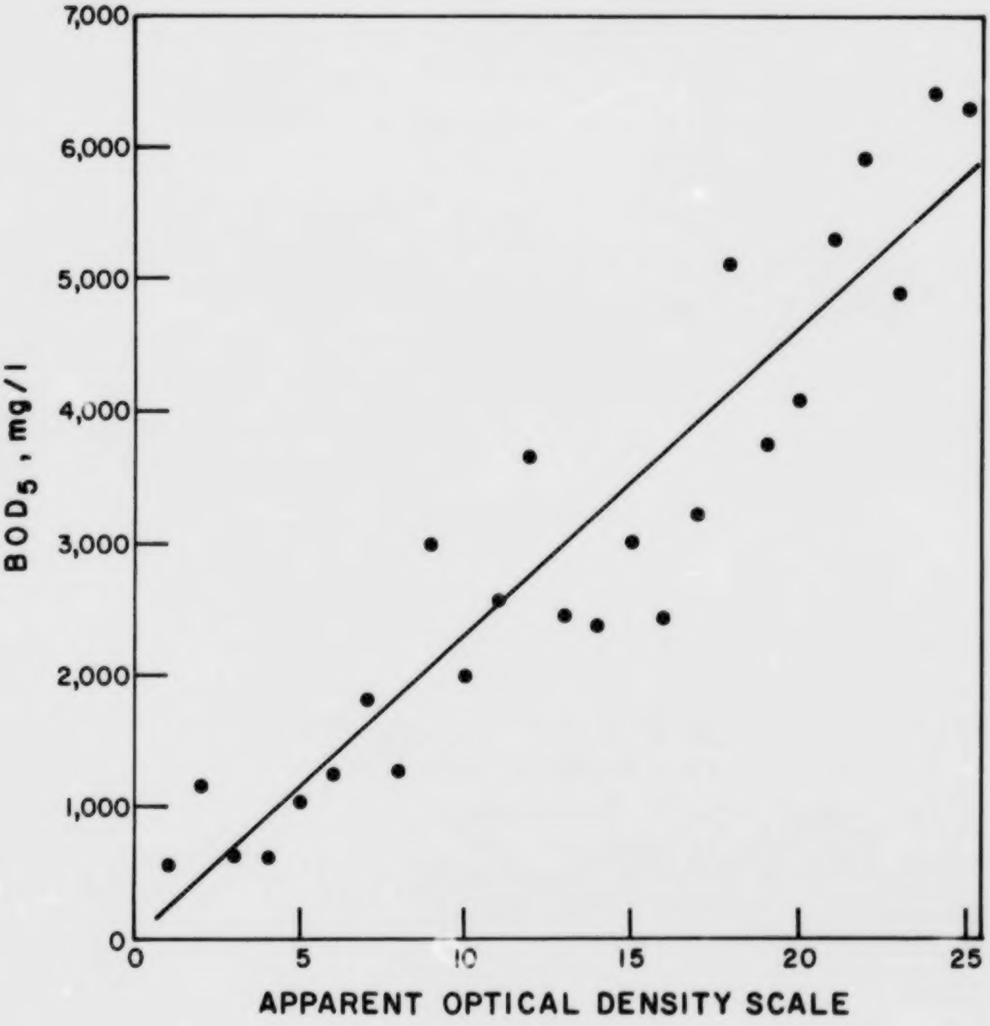

FIGURE 24. Qualitative relationships between an index of apparent optical density and the BOD_5 of the egg breaking wastewater.

11) After the egg strainer has been pumped free of egg, the cover is removed and the screenfilter is removed. This filter should be placed into a large shallow container where the chalazae solids can be scraped off and used as inedible egg product.

12) After all breaking and pasteurization has been completed, the blend tank or balance tank is filled with water and all empty product lines are connected. Water is pumped through the pasteurizer and also through the piping system. Instead of allowing the initial surge of liquid egg to escape from the end of the pipe system, it is suggested that the initial discharge be captured in a container, refrigerated and repasteurized for by-products. The problem encountered with this technique of product recovery is determining when to divert the flushings from the container of liquid egg already salvaged.

13) In smaller plants (1-3 breakers), it is economical to store the overflow and sump discharge from the egg washer and dispose of it daily to a sanitary landfill along with the egg shells. By segregating the wash water from the plants sewer system, the total BOD loading to be treated is reduced by at least 25%, yet the volume that has to be landfilled amounts to about 946-1135 liters (250-300 gallons) per washer per day.

In large plants (10-12 breakers) it may be uneconomical to collect and land dispose 9460-13626 liters (250-3600 gallons) a day. An alternative solution might be to try to recover the protein either by drying, chemical precipitation, or heat treatment.

The potential effectiveness of implementing these recommendations is shown in Figure 25. As indicated in this figure, the largest portions of waste can be controlled by management of the egg washer water and flushes from pipes and pasteurizers. However, the latter is a difficult recommendation to use and implement. In this study, elimination of the washer water and closer control over the other smaller losses were adopted at a low cost of labor and money to the individual egg breakers'

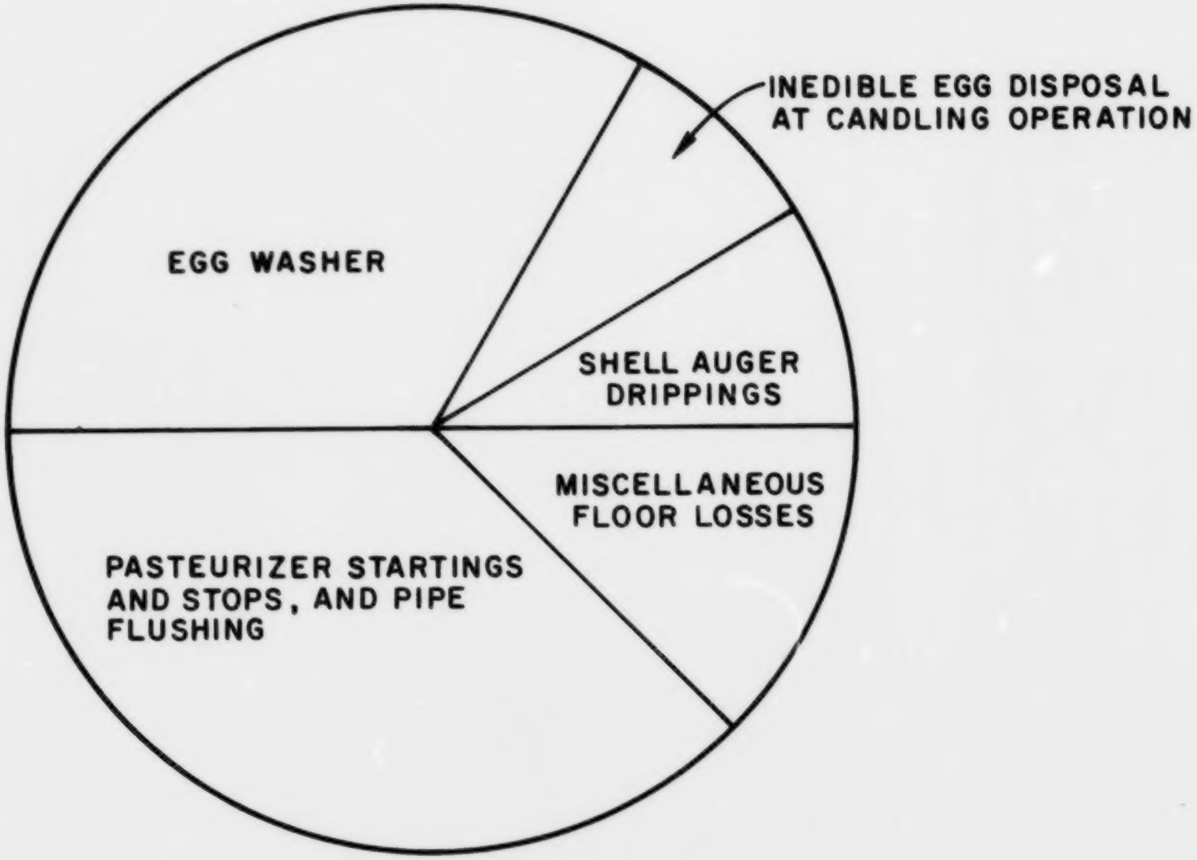

FIGURE 25. Approximate sources of organic waste loads generated in egg breaking unit operations.

operations with a resulting 50 percent average decrease in losses. Implementation of pipe flush control and other good management practice could probably lower product loss from the 3 or 4 percent loss, considered to be good for a well managed plant, to nearly 1 percent of the processed product. It is judged that 1 to 2 percent product loss represents the lower limit for practical in-plant waste management.

At the present time, eggs that are to be processed are shipped by truck from grading plants, poultry farms, chicken hatcheries, or retail stores to the breaking plant. Upon reaching the breaking plants, the eggs are removed from the cartons and the cartons are recycled to the distributor. After a number of recyclings the cardboard weakens and will collapse. Eggs in these types of cartons will become crushed or cracked. Leaking eggs will usually drain directly to the floor or else they will be loaded onto the egg washer where the contents are lost to the wash water. Breakage during shipment can be minimized by not recycling egg cartons but instead compacting them and selling the cartons as scrap paper. Until a more durable inexpensive carton material is developed, the recycling of cartons appears to reduce yields for the egg processors.

Since the major contributor to egg losses in the breaking industry is the egg washer, it seems logical that larger plants with multiple breakers could set aside one of its breakers to be preceded by a washer, to handle "dirties," and the remainder of the breakers could be operated without washers. Kraft, et al. have shown that commercially processed whole eggs resulting from both washed and unwashed eggs contain similar bacterial population counts. The same study concluded that product contamination is instead highly dependent upon sanitation practices during clean-up operations (28).

Results of bacteriological studies conducted in this study show that bacteria counts in egg washing liquids increase enormously over the four hour run periods. In fact, egg washing appears to contaminate egg surfaces rather than clean them. Data suggest that the washer would be probably more effective if it was used as an addition in the line sanitizer area. Experimental results of two 10 day periods at different locations are included in Appendix B.

By eliminating egg washers, eggs could be placed onto a short rubber roller conveyor belt. A stainless steel inclined apron to capture any leaking egg solids would be beneath the conveyor belt and it would guide them into a container. While on the conveyor belt, eggs would be carried over a candling operation and then sprayed with a chlorine solution before being transferred to the breaker.

The advantage of breaking eggs without first washing them is that egg processors will reduce the amount of egg product lost to the sewer and at the same time recover an inedible by-product. Assuming that egg processors lose .04 lb COD/dozen eggs of which 25% results from washers and 5.83×10^8 dozen eggs are broken annually, it is estimated that 12 million pounds of inedible liquid egg could be recovered by eliminating washers.

A piece of machinery common to all liquid egg processors is the breaker. This machine has two major shortcomings. The first is the size of the stainless steel apron which receives product drippings from the cups immediately after the egg solids are removed from the cups. When breakers are operating at 30-40 cases/hour the drippings are thrown outward as the cups proceed around the machine, but these drippings could be recovered by simply increasing the size of the steel apron. The breaker does not have a steel apron on its back side where cups pass into position to have eggs loaded onto the breaker. After cups pass through the cup washing portion of the breaker, they turn a corner which causes egg product to be thrown from the cups. It would be beneficial at this point to have an apron with elevated sides to collect egg drippings. This apron could be elevated to drain toward the breaker operator, with the product emptying into the edible product tray.

Plant E using eight breakers, operates in such a way as to recover product from tanks, vats, screens and an inclined auger. By conserving egg solids wherever possible, this plant has managed to make inedible eggs a profitable by-product. Over 1.5 years of production data for this plant were analyzed to show that the range of 70-110 lb of inedible egg/1000 lb of liquid eggs processed can be captured. This recovery represents a major fraction of pollution in most facilities. The average inedible product yield of 85.8 lb/1000 lb of processed eggs indicates that the egg breaking industry has capabilities of supplying the animal food industry with 60 million lbs of liquid egg annually, assuming 700 million lbs of liquid egg are processed annually. Inedible product recovered by conservation measures combined with the eggs resulting from the elimination of egg washers constitute a potential 72 million lbs of inedible egg annually.

Four of the five plants surveyed disposed of empty egg shells by trucking them to local sanitary landfills on a daily basis. One of the plants used an incineration system to reduce the moisture content of the shells from 30 percent to 2 percent (29). The dry product is more easily handled and stored, with no spoilage during periods when bad weather prevents disposal. Air drying also collects and retains the nutrients present in the adhering liquid portion of the shell (30), and may be an asset when sold to poultry feed producers (31).

Because of the initial capital costs, small breaking plants may not be able to afford to dry egg shells for use in chicken foods. However, as noted earlier, the trend for the future is fewer breaking plants and increased demand of processed liquid eggs. If this consolidation of breaking plants occurs, then the profitability of egg shell drying appears to be more likely for all plants. Assuming 20 million cases of egg at 47 lbs/case are processed each year, and 11 percent of an egg's weight is shell, the egg breaking industry has capabilities of providing nearly 53,000 tons of dried egg shells annually.

Once management has made in-house modifications to minimize egg product losses, it is essential that a system be devised to determine daily product losses. Relationships such as those shown in Figures 23 and 24 must be established between total solids and BOD or COD for each plant and correlated to egg concentrations in the wastewater. By investing in a weighing balance, evaporating dishes and a drying oven, and by knowing the daily flow and wastewater solids concentration, a plant operator could determine the daily plant losses.

Although egg processing accounts for only 10 percent of the nation's eggs and grading operations the remainder, the pollution potential of the processing industry is greater than that of the grading process. BOD losses from the grading operation of plant C amount to 0.001 lb BOD/dozen eggs graded, and work of Hamm et al. (32) indicate that egg grading losses average 0.0014 lb BOD/dozen. Results of this study show that losses ranging from 0.02 to 0.01 lb BOD/dozen occur in egg breaking plants after modifications have been implemented. Therefore, egg breakers handle 10 percent of the country's eggs, but the losses per dozen are tenfold higher than losses of grading operations.

PART III

EGG BREAKING INDUSTRIAL WASTEWATER TREATABILITY STUDIES

SECTION I

INTRODUCTION

GENERAL

As part of the increased public environmental awareness, new laws and regulations are being instituted to control all point sources of industrial wastes. Included under the Federal Water Pollution Act Amendments of 1972 are discharges resulting from egg processing operations. Egg breakers are faced with four options of discharging their wastewaters in attempting to comply with existing legislation. First, they may obtain a permit to treat and discharge the wastewater directly to surface waters. Second, pretreatment may be utilized to decrease the pollutants to levels of domestic sewage for discharge to a municipal treatment system. A user charge will be assessed to industries adopting this alternative. The third option is to discharge untreated wastes directly to a municipality and pay a user's charge plus a surcharge which will be related to the egg processor's waste contribution. Finally, the industry may consider reusing or no direct discharge by using land application.

Extrapolation of a recent study of wastewater problems in egg breaking plants (22) indicates that as many as 75 facilities are presently experiencing difficulties in the treatment of their effluents. It might also be estimated that a large portion of those that are not aware of the problem will experience difficulties in conforming to new federal and state regulations in the near future.

A review of the literature has revealed an almost complete lack of necessary design criteria to enable the design of egg waste treatment facilities. In order for consultants to advise clients on the treatment scheme which will yield desired results, more detailed treatability data must be accumulated. The general goals of this portion of the study were to develop data on the feasibility of control of egg breaking plant effluents and to determine engineering design criteria that could be used to design wastewater treatment processes. The alternative situations under which the feasibility of treatment was determined was the first three waste treatment alternatives outlined above. The fourth alternative of effluent reuse or land disposal was not examined. Reuse of wastewater in the food industry is usually not advisable, and land discharge of these concentrated wastes would probably require significant available acreage.

LOCATION

Treatability studies were conducted on wastewaters from egg breaking operations in New York State. Samples were obtained from two plants after first reducing the plants' waste loads through in-plant modifications. The two plants studied are identified as Plant A and Plant B in the report.

OBJECTIVES

The background data on the variability and composition of wastewaters given in Part II indicate that the egg breaking wastewaters will present difficult treatment problems. The size of the industry also is a problem since the largest has a production capacity less than 150,000 dozen per day (about 180,000 lb/day) and a total design waste flow of less than 200,000 gallons per day. This flow is equivalent to the volume of sewage from a community of 2000 people. It is especially difficult to provide an efficient and inexpensive waste treatment system for such small but highly contaminated waste flows. Thus the limitations of this portion of the study included development of efficient, inexpensive and simple waste treatment approaches that could provide varying levels of treatment. The specific objectives were to:

1. Determine the efficiency of several conventional biological waste treatment processes in handling egg breaking wastewaters.
2. Utilize the initial data to develop a series of waste treatment alternatives that will produce a given removal efficiency at a minimum cost in terms of capital investment and energy.
3. To develop engineering design criteria for a number of aerobic and anaerobic treatment processes.

In development of the data in this section it should be noted that initial emphasis was placed on the use of aerobic systems such as aerated lagoons and activated sludge because it was felt that disagreeable odors would rule out the use of anaerobic processes. However, anaerobic lagoons were examined because of their small energy and maintenance requirements. As will be shown, anaerobic processes were surprisingly efficient and did not generate the expected unpleasant odors.

SECTION II

THEORETICAL CONSIDERATIONS

Four types of treatment systems were examined in this study - aerated lagoons, activated sludge, anaerobic lagoons, and rotating biological contactors. Inexpensive means of improving the efficiency of treatment with combination of anaerobic and aerobic lagoons were examined. Also since the effluent from egg breaking plants was highly biodegradable it was felt that incorporation of mixing theory by having several small completely mixed units in series as opposed to one large unit would be advantageous and this concept was also tested. A summary of the background theory for the various systems used in this treatability study follows.

AERATED LAGOONS

An aerated lagoon is a dilute, completely mixed unit operating without solids recycle. The lagoon is often an earthen basin with elevated banks to minimize water losses due to wave action caused by aeration units (33). Oxygen is supplied to the lagoon by either diffused aerators, surface aerators or sparged air turbine systems.

Aerated lagoons have been used successfully in the treatment of a number of food processing wastes including peas, pear, peach, apple and dairy (34). This treatment process has experienced widespread use because it requires little operational control. Biological equilibrium will be established with time and will adjust automatically to absorb various changes in loads. The absence of the need for complex mechanical maintenance other than lubrication and periodic inspection also makes the aerated lagoon an attractive treatment process.

The design of a completely mixed aerated lagoon can be based on the fundamentals of a completely mixed biological reactor. Assuming that first order substrate removal kinetics and complete mixing exists, the following equation is obtained from a mass balance of the system (37,38):

$$\frac{S_1}{S_o} = \frac{1}{1 + Kt} \qquad (1)$$

where S_o = the influent soluble substrate concentration (mg/ℓ COD)

S_1 = the effluent soluble substrate concentration (mg/ℓ COD)

K = the substrate removal coefficient

t = the reactor detention period (days).

By plotting empirical values of S_o/S_1 for varying values of detention times a removal coefficient K can be determined from the slope of the line.

CONSECUTIVE COMPLETE MIX REACTORS

Theoretically, plug flow treatment systems are more efficient than complete mix systems in stabilization of wastes (36). The main disadvantage of plug flow systems is their susceptibility to shocks and upsets. True plug flow systems can be approximated by dividing an aeration basin into a series of complete mix reactors and still maintain an ability to withstand shock loads (37). Assuming that all of the reactors in series are completely mixed and first order substrate removal kinetics apply, the required volume approaches that required for a true plug flow reactor. A system of four reactors in series will theoretically require 43% of the volume required for 85% removal efficiency with one complete mix reactor. This decrease in required volume becomes more pronounced as desired treatment efficiency increases. For example, four reactors in series require 14% of the volume of one reactor for 98% removal efficiency and would obviously result in decreased capital and operating costs.

Removal coefficients for reactors in series can be determined by applying the same theory discussed for aerated lagoons. In this case the effluent from one reactor becomes the influent of the next and the removal functions become:

$$\frac{S_e}{S_o} = \frac{1}{(1 + Kt)^n} \qquad (2)$$

where S_e = the effluent substrate concentration

S_o = the influent substrate concentration

t = the detention time of one reactor

K = the substrate removal coefficient

n = the number of reactors

ROTATING BIOLOGICAL CONTACTOR (RBC)

The rotating biological contactor is in use in Europe and is now being used in the United States for treatment of certain municipal and industrial wastes (38,39). A number of investigators have documented the fact that the RBC system has handled shock loads, operated at short detention times, resulted in low operation and maintenance costs, and produced a rapidly settling and readily dewatered sludge (40).

Modeling a RBC system requires that substrate and organisms be related on a mass basis (e.g. Kg COD/Kg microbial solids) (41). Estimates of the microbial active mass on the rotating discs are difficult to obtain so an empirical approach has been taken to provide design relationships. The usual means of reporting design criteria is based on loading rate of organics applied per surface area of disc. By reporting organic loading as opposed to hydraulic loading, results can be used to determine the effect of waste streams of variable quality.

ANAEROBIC LAGOONS

Anaerobic lagoons are earthen basins specifically designed to destruct and stabilize organic matter. Since mechanical mixing is rarely provided, anaerobic lagoons act as sedimentation units which may result in gradual buildup of solids. The rate of solids accumulation is a function of solids loading, degradability of influent solids and growth kinetics of the biological population. The rate of solids accumulation will determine how often solids will have to be removed.

Anaerobic lagoons have been used successfully for treatment of high strength industrial wastes including canning wastes, meat packing, paper, textiles and sugar (42). The present design criteria that exist for anaerobic lagoons are strictly empirical and based on an organic loading basis (lb BOD_5 or COD/1000 ft^3/day). Typical values of loading rates ranged from 4-33 lb BOD/1000 ft^3/day (43).

Due to the high loading rates with anaerobic lagoons, there will undoubtedly be significant oxygen demand, solids and nutrients escaping in the effluent. If the effluent is to be discharged to surface waters, further polishing will be necessary. Additional treatment can be attained by use of an oxidation pond or an aerated lagoon. Anaerobic-aerobic treatment combinations have previously been shown to produce 95% BOD removals for meat packing industry wastewaters (44).

ACTIVATED SLUDGE

The activated sludge process is a complete mix aerobic system followed by solids separation and recycle. Microbial solids resulting from gravity separation are partially recycled or wasted. The advantage of solids recycle is improved effluent quality without increased reactor volume.

The two common approaches to modeling activated sludge processes are the food to microorganism ratio (F/M) and solids retention time (SRT) techniques. Similar design parameters can be obtained from both techniques but the SRT technique is a more rational operation and control method. The SRT technique is not affected by changes in the feed solids or influent organic strength, as in the F/M technique. A simple continuous hydraulic wasting procedure can be used with the SRT technique, resulting in a more uniformly operated biological system (45).

Lawrence and McCarty have developed a SRT model and have shown that at steady state conditions the SRT is the inverse of the biological growth rate (48). The following definitions and equations were developed in their model.

$$SRT = \frac{M}{\Delta x/\Delta t} = \frac{XV}{X_r W + X_e\ (Q-W)} \qquad (3)$$

$$U = \Delta S/\Delta t\ M = \frac{Q(S_o - S)}{XV} \qquad (4)$$

$$U = \frac{KS}{K_s + S} \qquad (5)$$

$$\frac{1}{SRT} = YU - b \qquad (6)$$

$$\frac{dx}{dt} = \frac{YdS}{dt} - bX \qquad (7)$$

where S_o = the influent soluble substrate (mg/ℓ)

S = the soluble substrate at any time (mg/ℓ)

X = the aeration tank MLSS concentration (mg/ℓ)

X_r = the recycle suspended solids concentration (mg/ℓ)

X_e = the clarifier effluent suspended solids concentration (mg/ℓ)

dx/dt = the net increase in biological solids as a result of synthesis and endogenous respiration (mg/ℓ-day)

dS/dt = $\Delta S/\Delta t$ = the rate of substrate removed per day (lb/day)

M = biological mass in system (lb)

$\Delta x/\Delta t$ = the biological mass wasted per day (lb/day)

U = the specific substrate utilization rate (day^{-1})

Y = the solids yield coefficient (mg cells/mg substrate removed)

W = the solids volume wasted (gal./day)

V = the volume of aeration tank (gal.)

K = the maximum substrate removal coefficient (day^{-1})

K_s = the soluble concentration at which the growth rate is half the maximum rate

b = the microorganism decay coefficient (day^{-1})

Q = the flow (gal./day).

Since activated sludge processes require artificial aeration, the oxygen requirements for the system should be estimated. This can be accomplished by assuming oxygen utilization results in substrate oxidation and endogenous respiration. The following equation results:

$$\frac{dO_2}{dt} = a' \frac{dS}{dt} + b'X \tag{8}$$

where dO_2/dt = the oxygen required (mg/ℓ-day)

a' = the oxygen required for oxidation of substrate for energy (mgO_2/mg substrate removed)

b' = the oxygen required for endogenous respiration (mg O_2/mg solids auto-oxidized/day).

It must be remembered that Equations 3 through 8 were developed on the assumption that the influent waste stream is a soluble substrate. In practice, wastewaters contain inert influent suspended solids which will increase the apparent yield coefficient due to absorption of solids to the active biological floc rather than being oxidized and utilized for energy and cell synthesis (35). However, if the influent suspended solids are hydrolyzed in the aeration basin and become available as substrate the SRT technique becomes valid.

SECTION III

MATERIALS AND METHODS

BENCH SCALE APPARATUS AND FEEDING PROCEDURES

Aerated Lagoons

Aerated lagoons were simulated using 75 liter (20 gal.) units at a volume of 30 liters with a surface area of 2322 cm^2 (2.5 ft^2). Oxygen was transferred to water by means of three air stones. The system was seeded with mixed liquor suspended solids from a local activated sludge sewage treatment plant. During a seven to ten day acclimation period egg processing wastes were initially applied to the lagoons at rates well below designed loading rates. The lagoons were fed on a fill and draw basis, usually once per day, with distilled water added to account for evaporation losses. Figure 26 shows one of the laboratory models.

Consecutive Complete Mix Reactors In Series

This aerobic treatment process consisted of a 30 liter total liquid volume unit which was partitioned into 5 compartments. The surface area of each compartment was 464 cm^2 (.42 ft^2). Mixed liquor from one cell could only flow to the next cell through a 1.27 cm (.5 in.) hole drilled in the plexiglass partitions. This unit is shown in Figure 27.

Activated Sludge

The activated sludge system consisted of a 5.5 liter aeration reactor followed by an 800 ml clarifier. The surface area of the aeration basin was 251 cm^2 (.27 ft^2) and the area of the clarifier was 102 cm^2 (.11 ft^2). The effluent from the aeration basin flowed by gravity

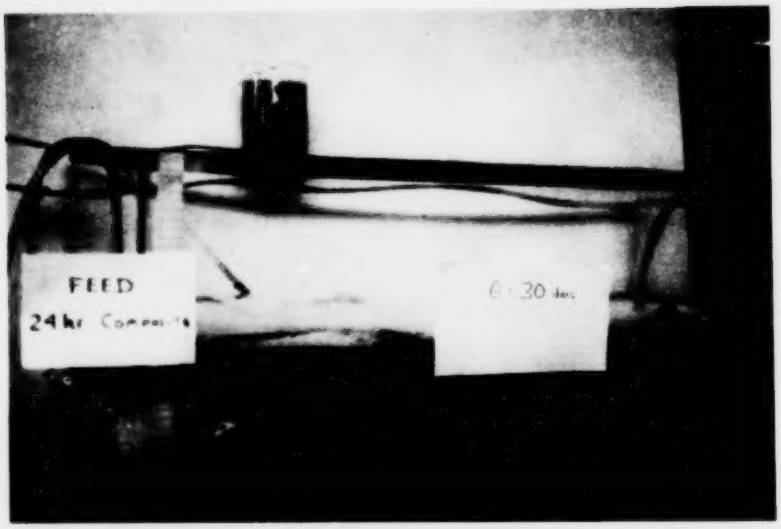

FIGURE 26. Bench scale model of the aerated lagoon process

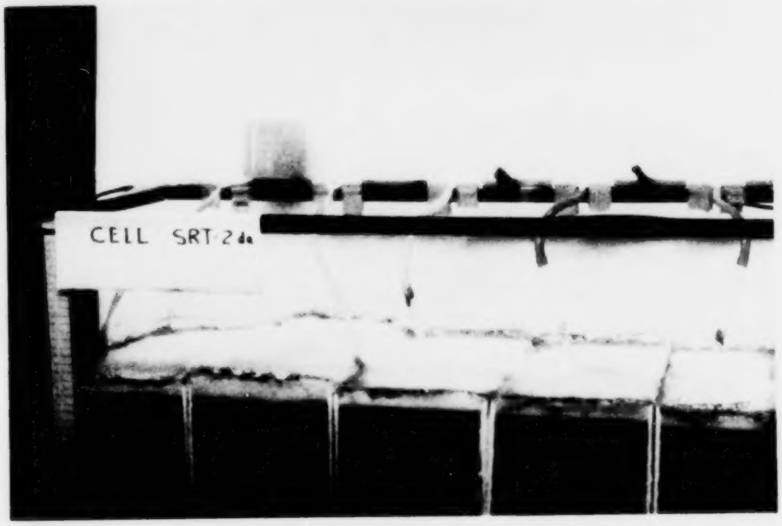

FIGURE 27. Baffled aerobic lagoon used to examine the treatability of egg breaking industrial wastewaters.

to a center feed clarifier and overflow from the clarifier was collected for future analysis (Figure 28).

The aeration basin was seeded with mixed liquor from one of the aerobic lagoons that was acclimated at an earlier time.

Substrate was pumped continuously over a 16-hour period to the unit from a nearby cooler maintained at 10°C. By using a time clock to control the feeding schedule it was possible to simulate the usual length of time which an egg processing plant produces wastes. The same pump which transferred feed to the aeration chamber was also used to recycle sludge from the clarifier to the complete mix reactor. Solids were wasted from the clarifier in order to maintain a specific solids retention time (SRT).

Rotating Biological Contactor

Unlike all the other treatment schemes which were operated under laboratory conditions, the rotating biological contactor (RBC) was maintained at the site of Plant B.

The RBC system is made up of 36 polyethylene discs with diameters of 47.3 cm (18 5/8 in.). The liquid volume of the unit is 136 liters (36 gal.). The effective surface area of the discs is 23.3 m^2 (250 ft^2). The discs were operated at 13 rpm's and were fitted with plastic extensions to help maintain the sloughed solids in suspension (Figure 29).

The RBC module was initially filled with a diluted egg processing wastewater and seeded with mixed liquor solids from a municipal activated sludge plant. The RBC system was operated for four days on a fill and draw basis 37.8 ℓ/day (10 gal./day). Once a light brown growth had appeared on the discs, the feed to the RBC was applied on a continual basis for the duration of a processing day, approximately 16 hours. The

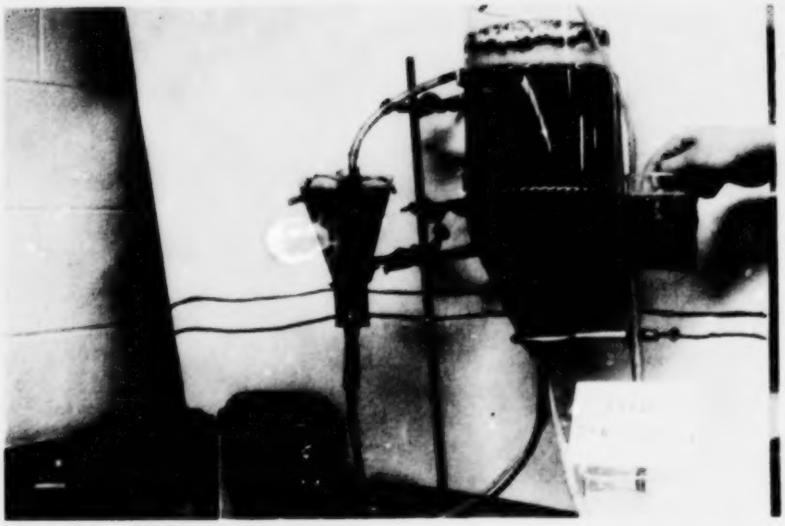

FIGURE 28. Laboratory scale activated sludge unit used to examine the treatability of egg breaking industrial wastewaters.

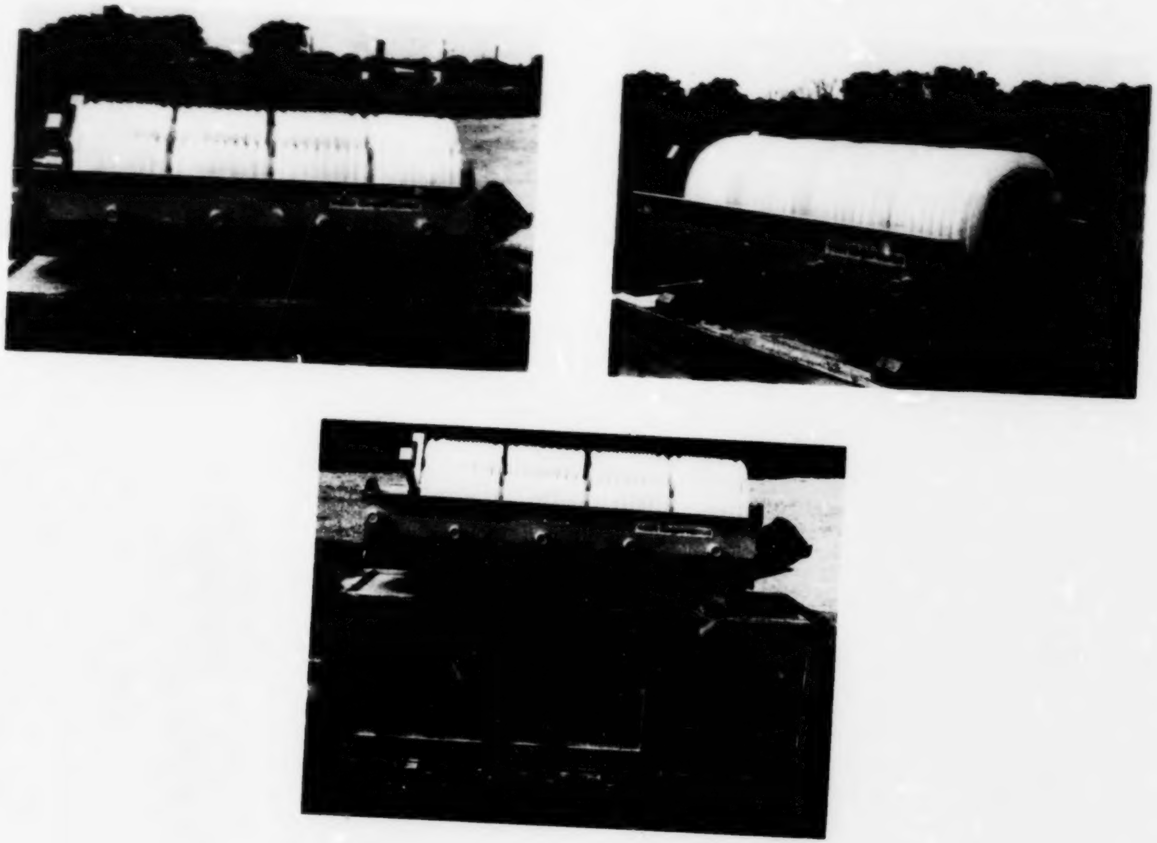

FIGURE 29. Rotating biological contactor unit used to examine the treatability of egg breaking industrial wastewaters. (Photographs courtesy of Autotrol Corp.)

wastewater was transferred directly from Plant B's effluent pipeline by a variable speed pump, to the first cell of the RBC system. A time clock was installed to feed the RBC at a constant flow rate during the normal period that eggs were being processed.

The effluent from the RBC was directed to a clarifier with a surface area of 582 cm^2 (.626 ft^2). The clarified effluent then overflowed a container which stored the entire treated volume. After a day's operation the clarified effluent was analyzed and the excess settled solids were removed from the clarifier to determine excess sludge production.

Anaerobic-Aerobic Processes

The anaerobic lagoons were identical in size to the bench scale aerobic lagoon units. The volume at which the anaerobic lagoons were operated was 30 ℓ. The aeration basins which followed the anaerobic lagoons were similar to reactors used in the activated sludge process and all secondary aerobic units had a detention period of six days.

The anaerobic lagoons were initially filled with tap water and then seeded with anaerobic solids obtained from a municipal anaerobic digester. Egg processing wastes were added to the anaerobic lagoons on a fill and draw basis. For the first week of operation the volume used in the fill and draw procedure was 1 ℓ/day. After the lagoon seemed to be adapting to the new substrate the volume of feed was increased to maintain the designed hydraulic retention time (HRT).(See Figure 30).

The aeration chambers which followed the anaerobic lagoon were seeded with mixed liquor from the bench scale activated sludge unit and from a nitrifying population used in the stabilization of poultry wastes. Effluent from the anaerobic lagoons was supplied to the aeration basins

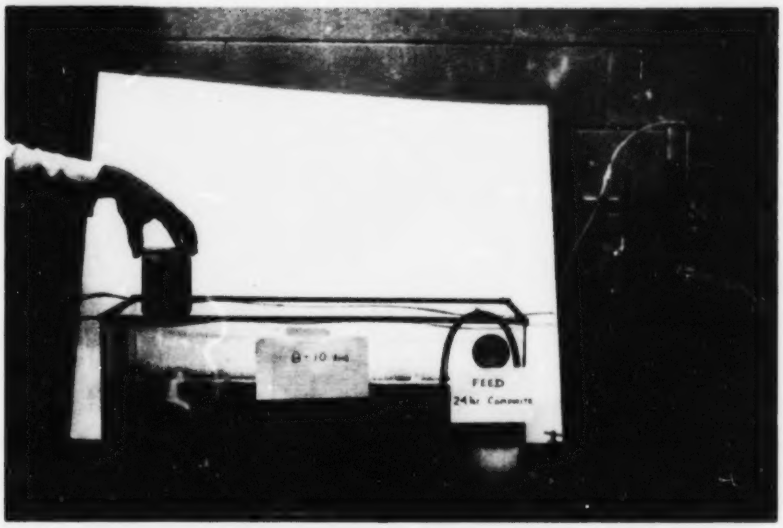

FIGURE 30. Series anaerobic lagoon (20 day SRT) and aerobic lagoon (6 day SRT) used to examine the treatability of egg breaking industry wastewaters. (The light beaker contains the feed substrate and the dark beaker the SS of the anaerobic lagoon.)

on a fill and draw basis. Complete nitrification has been documented as occurring 1.3 - 2.9 days SRT at 20°C and at approximately 4 days SRT at 8°C (47,48,49). The SRT value of 6 days used in this study was chosen to be capable of achieving complete nitrification.

In conjunction with the single cell anaerobic lagoon followed by an aeration basin another anaerobic treatment scheme was developed. This system was a five-celled anaerobic lagoon with dimensions identical to the five chambered aerated lagoon described earlier. The HRT of each anaerobic cell was 2 days and the volume of each chamber was 6 liters. This anaerobic system was followed by a 6 liter aeration chamber operated at a SRT and HRT of 6 days. The dimensions of the aeration chamber were identical to those used in the single cell anaerobic-aerobic treatment schemes. Egg processing wastewater was fed to the first cell of the multi-cell anaerobic system at a nearly constant feed rate over an eight hour time period.

The effluent from the anaerobic lagoon's last cell was used to feed the aeration chamber on a fill and draw basis once each day.

SOURCES AND COLLECTION OF EGG BREAKING WASTEWATERS USED IN TREATABILITY STUDIES

Two egg breaking plants (Plant A and B) located within a twenty mile radius of Cornell University were chosen as sources of laboratory feed wastewater. In-plant modifications had been completed prior to use of the wastewater in treatability studies.

Collection of wastewater samples for treatability studies was obtained by using an automatic Sigmamotor sampler. Ten equal volume samples were automatically collected every hour for the entire egg processing work day. The samples collected throughout the day were automatically pumped to a plastic sample storage bottle which was stored in an ice-filled styrofoam cooler. Enough sample was collected in one day to provide a two day supply of feed for the bench scale treatability units. The portion of feed not utilized on the first day was stored at 10°C and then used as a feed for the following day. The bench scale units were fed for a total of five days per week in an attempt to simulate the actual egg processing operation.

The wastewater characterization shown in Part II indicated that the BOD_5:N:P weight ratio was less than the optimum 100:5:1 desirable for aerobic treatment processes. A phosphorus buffer was used to supplement the feed during the aerobic lagoon and activated sludge studies. However, no phosphorus was added with the anaerobic processes.

ANALYTICAL PROCEDURES

The egg processing wastes which were fed to the various treatment processes and the resulting treated effluent were analyzed for a number of characteristics. Total solids, total alkalinity, ortho-phosphate and BOD_5 determination were made in accordance with procedures outlined in Standard Methods (50). Ammonia and Kjeldahl nitrogen were determined as described by Prakasam et al. (51). Both nitrogen analyses are identical to procedures presented in Standard Methods except for the use of micro-Kjeldahl digestion and distillation equipment. COD values were obtained by use of the COD test presented by Jeris (52).

Additional analyses performed included suspended solids, by use of a Millipore filter apparatus and #9-873B (2.4 cm. dia.) Reeves Angel glass fiber filters. Dissolved oxygen determinations and oxygen uptakes were determined by a Y.S.I. Model 54 D.O. meter. Effluent turbidity of certain treatment processes was determined using a Hach Model 2100 turbidimeter.

SECTION IV

RESULTS OF TREATABILITY STUDIES

AERATED LAGOONS

The performance of aerated lagoons is illustrated in Figures 31 and 32 and the data are summarized in Tables 23 and 24. All data are the average of five or more days of operation during which no change in effluent characteristics was noted. This steady state condition was obtained in most tests after 10 or 20 days of unit operation. The lagoons were maintained at hydraulic retention periods (θ) of 10, 20 and 30 days.

All lagoons operated at near neutral pH for the entire steady state period. The 20 day lagoon fed from wastes of Plant A shows a low pH of 6.2 and low alkalinity. The loss of alkalinity, low pH and high nitrate levels indicates an active population of nitrifying organisms which consumed most of the bicarbonate alkalinity and destroyed still more buffering capacity through the production of hydrogen ions. The ammonia nitrogen levels ranged from 0 to 4.6 mg/ℓ as N, nitrite nitrogen concentrations from 0.1 to 4.5 mg/ℓ as N, and nitrate nitrogen in the range of 24 to 48 mg/ℓ as N, thus indicating that nitrification was quite efficient. In full-scale units it may be necessary to add alkalinity to the lagoon for efficient operation.

Oxygen uptake obtained from the bench scale lagoons showed a definite decrease in oxygen requirements from 25.3 to 7.0 mg/ℓ/hr as the hydraulic retention period increased from 10 to 30 days. The aerated lagoons treating Plant A were capable of reducing a total influent COD ranging from 4000 to greater than 6000 mg/ℓ to a soluble effluent COD less than 700 mg/ℓ at all three hydraulic retention periods. The relationship between the total effluent COD produced and the soluble COD is shown in the unit treating the effluent from Plant B (Figure 32).

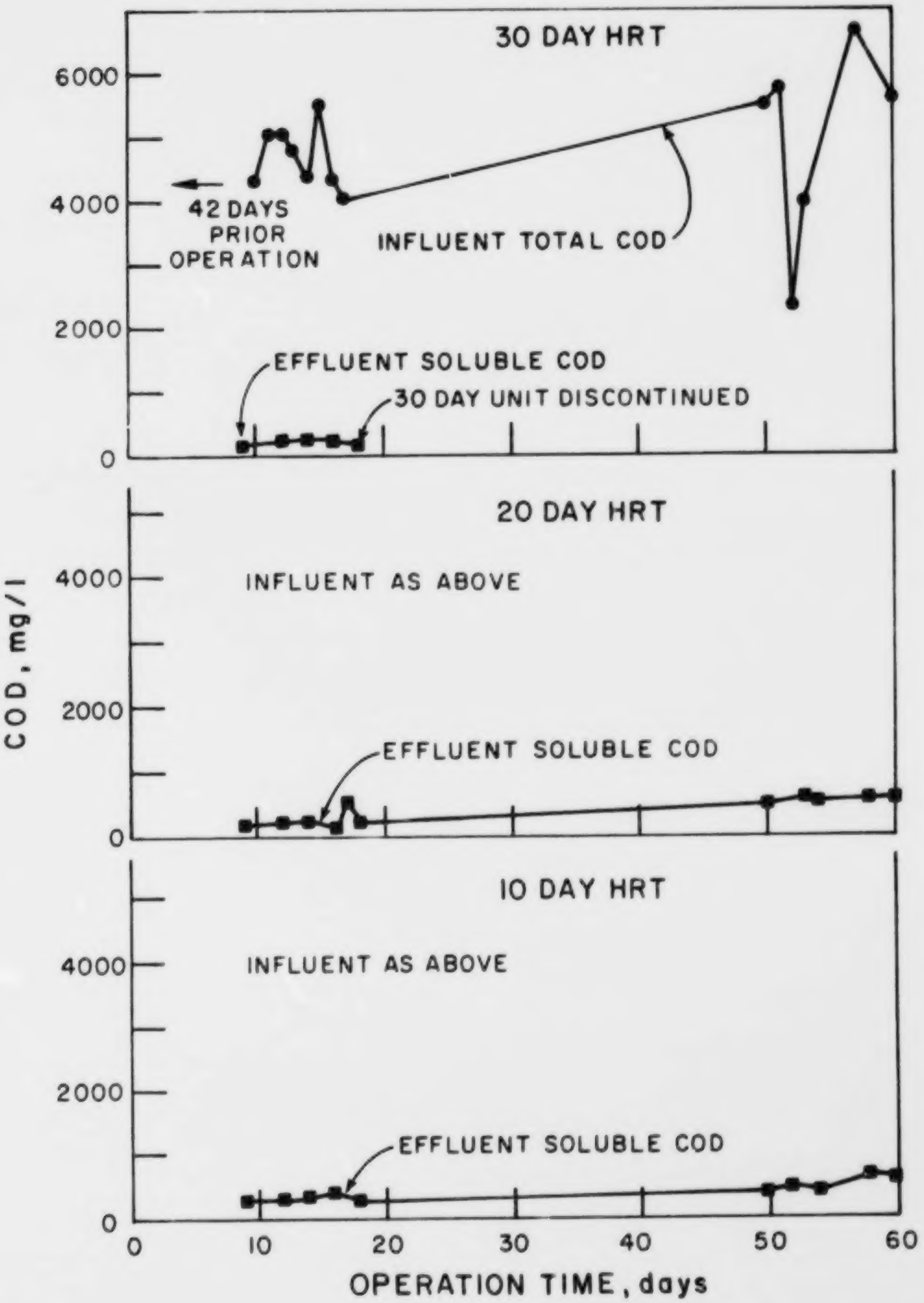

FIGURE 31. Aerobic lagoon treatment of total egg breaking wastewater from Plant A at 20°C.

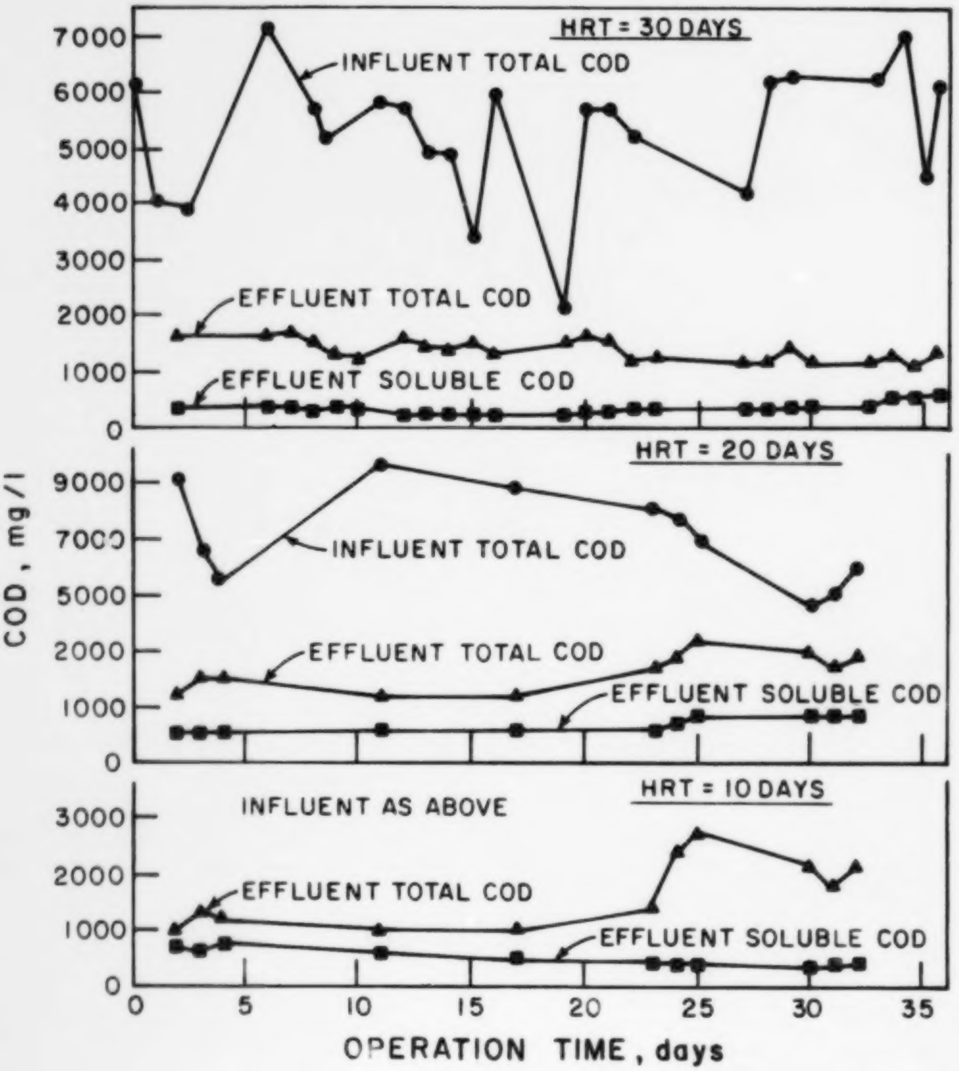

FIGURE 32. Aerobic lagoon treatment of total egg breaking wastewater from Plant B at 20°C.

With an influent total COD ranging from 5000 to 10,000 mg/ℓ, the soluble effluent was consistently less than 1000 mg/ℓ, with the total COD about double the soluble COD. Even though these results indicate that aerated lagoons are capable of soluble COD removal efficiencies greater than 90 percent, the quality of effluent is not good enough to satisfy effluent discharge requirements. The units also had a sharp pungent odor for aerobic treatment processes.

Table 23. SUMMARY AERATED LAGOON CHARACTERISTICS AND REMOVAL EFFICIENCIES

	Lagoon Characteristics					
	Plant A			Plant B		
	Hydraulic retention period, days					
Parameter	10	20	30	10	20	30
SS (mg/ℓ)	1,050	560	550	890	1,300	850
Oxygen uptake rate (mg/ℓ/hr)	-	9.3	7.3	25.3	13.8	7.0
Removal efficiency (%)						
COD, total	59.8	72.3	81.1	69.2	66.1	76.5
COD, soluble	89.7	88.3	96.2	86.9	93.7	94.3
TKN, total	64.2	41.2	64.9	51.1	49.8	58.7

Effluent total TKN values show that removals of organic nitrogen range from 41% to 64% depending on the hydraulic retention time.

Throughout the study period it was noted that when the effluent from any one of the aerated lagoons was allowed to settle in a 1000 ml cylinder the percentage of suspended solids actually settling to the base of the cylinder was minimal. The biological flocs formed in these

Table 24. AERATED LAGOON INFLUENT AND EFFLUENT CHARACTERISTICS TREATING WASTEWATER FROM PLANT A AND B. LAGOON TEMPERATURE 20°C. (All units in mg/ℓ unless otherwise noted, mean values; $5 < n < 10$.)

	INFLUENT WASTEWATER						TREATED EFFLUENT					
	Plant A			Plant B			Plant A			Plant B		
	Hydraulic detention period, days						Hydraulic detention period, days					
Parameter	10	20	30	10	20	30	10	20	30	10	20	30
COD, total	4980	4980	5130	6300	6300	5850	2000[a]	1380[a]	970	1940	2140	1370
COD, soluble	-	-	-	-	-	-	509	581	191	825	390	333
TKN, total	201	201	234	295	295	298	72	118	82	144	148	123
pH	-	-	-	-	-	-	7.2	6.2	7.1	7.3	7.0	7.4
Alkalinity as $CaCO_3$	-	-	-	-	-	-	71	29	68	157	105	127
NH_3-N	-	-	-	-	-	-	0	4.6	0	1.0	0.4	1.2
NO_2^--N	-	-	-	-	-	-	0.1	4.5	1.0	1.1	1.2	0.5
NO_3-N	-	-	-	-	-	-	4.3	46.0	28.3	24.5	43.5	47.4

[a] estimated from weight:COD relationships

systems were dispersed in nature and did not resemble floc formations of typical municipal treatment systems. The SS of the effluent varied from 560 to 1,300 mg/ℓ and imparted a highly turbid yellow appearance to the effluent.

The ratio of influent total COD (S_0) to effluent soluble COD (S_1) was plotted against HRT of the aerated lagoons in order to determine the substrate removal coefficient (Figure 33). The removal coefficients (K) were 0.76 day^{-1} and 0.58 day^{-1} for Plants A and B, respectively.

CONSECUTIVE COMPLETELY MIXED REACTORS

A second aerobic treatment process investigated was a system of completely mixed reactors in series. It was of interest to determine treatment efficiency of a simulated plug flow system and compare the results to those obtained by a single cell lagoon of an equal overall HRT at the same temperature.

Results of the 5 cell aerated system are outlined in Table 25. Effluent quality expressed as total COD and soluble COD from this multiple cell treatment system is illustrated in Figure 34. There was not a substantial decrease in pH throughout the reactors in series but there was evidence of alkalinity reduction due to the nitrification. Nitrate concentrations of 22 mg/ℓ are similar to nitrate values experienced in a single cell aerated lagoon (24.5 mg/ℓ NO_3-N) and thus indicate similar efficiencies of nitrification between single cell vs. multi-cell treatment. It is impressive to note that retention of the wastewater for 10 days in the 5 cell unit produced removal efficiencies equal or greater than those obtained at a retention period of 30 days in a one cell unit.

In comparing overall removal efficiencies of the 5-cell system to those of a single cell lagoon of an equal or larger detention time (Table 23) it becomes evident that consecutive complete-mix reactors do in fact increase COD and TKN removals.

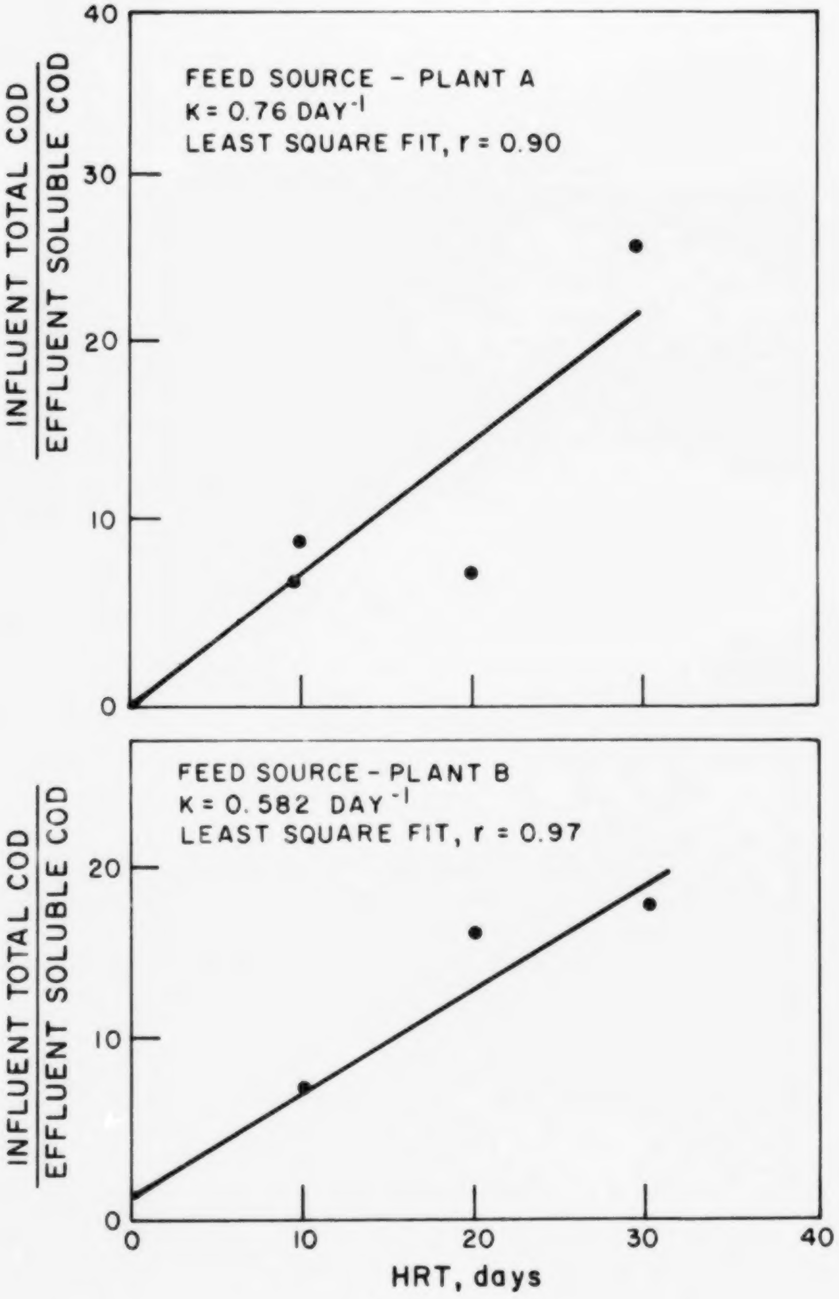

FIGURE 33. Determination of substrate removal coefficients for aerated lagoons treating wastewaters from Plants A and B at 20°C.

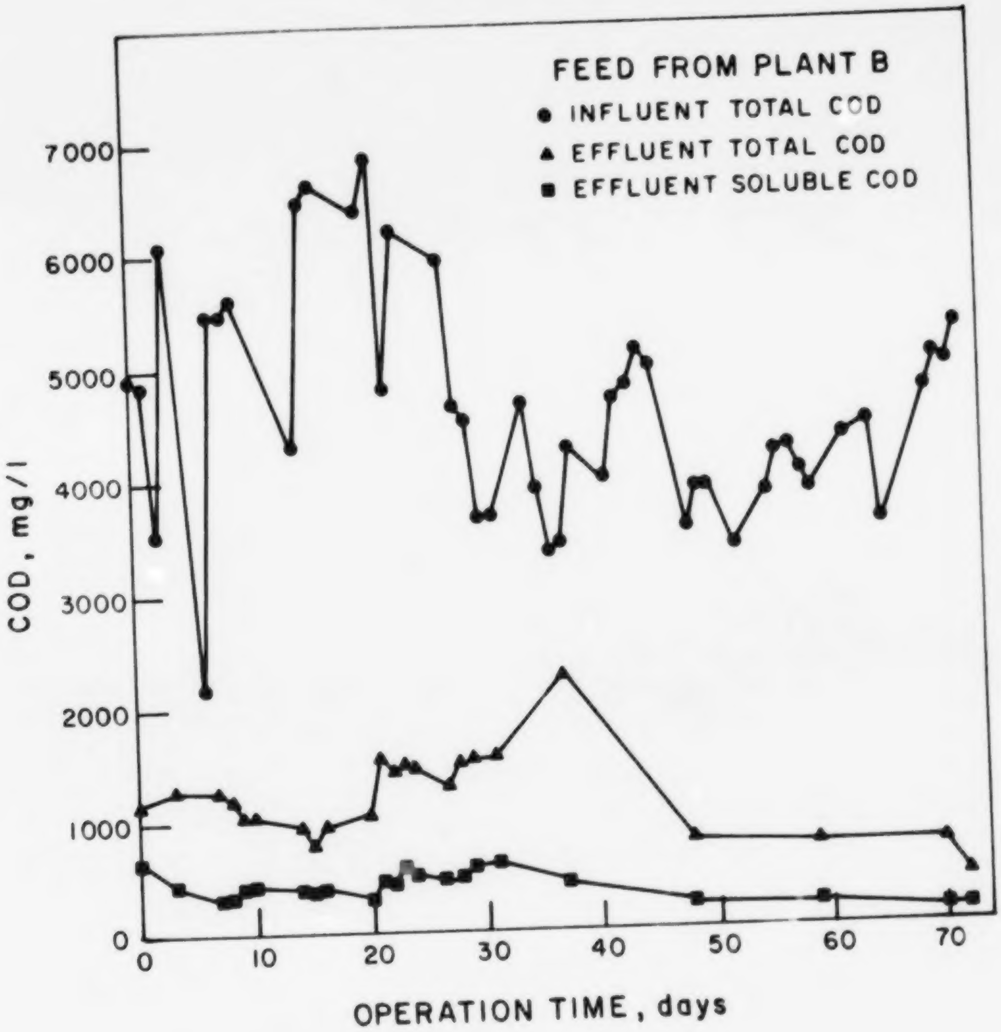

FIGURE 34. Aerated lagoon treatment composed of 5 cells connected in series with a hydraulic detention period of 2 days each at 20°C.

Table 25. CHARACTERISTICS OF 5-CELL AERATED LAGOON OPERATED AT 20°C WITH A TOTAL LIQUID RETENTION PERIOD OF TEN DAYS (2 DAYS IN EACH CELL) (All quantities in mg/ℓ unless otherwise noted, mean values $5 < n < 25$)

Parameter	Influent	Cell no. 1	3	5
COD, total	4490	3600	2040	675
COD, soluble	-	280	220	180
TKN, total	236	271	155	58
SS	-	2910	1610	380
pH	-	7.5	7.4	7.4
Alkalinity, as $CaCO_3$		266	218	176
Oxygen uptake, mg O_2/ℓ/hr	-	27.6	15.0	4.8
NH_3-N	-	9.1	4.2	1.7
NO_2^--N	-	-	-	0.5
NO_3^--N	-	-	-	22
Turbdity	-	-	-	99
Removal Eff., % (Accumulative)				
COD, total	-	19.8	54.7	84.9
COD, soluble	-	93.8	95.1	95.9
TKN, total	-	-	34.3	75.4

Table 26 shows a comparison of removal efficiencies in various aerobic lagoons.

Table 26. COMPARISON OF ONE COMPLETELY MIXED UNIT AND MULTI-CELL AEROBIC LAGOON TREATMENT OF EGG BREAKING WASTES

	Process Efficiency of Removal, %		
Aerobic system @ 20°C	Total COD	Soluble COD	Total TKN
5-cell 10 day aerated lagoon	84.9	95.9	75.4
Single cell 10 day aerated lagoon	59.8-69.2	86.9-89.7	51.1-64.2
Single cell 30 day aerated lagoon	76.5-81.1	94.3-96.2	58.7-64.9

It was of value to note the high effluent turbidity of the 5-cell aerated system of 99 JTU's. The poor settleability of the suspended solids and a residual yellow color which was also prevalent in effluents of single cell aerated lagoons may very well prevent the use of multi-cell aeration systems in the production of wastewater effluents for direct discharge to surface waters. However, this unit would appear to be a good alternative for pretreatment in preparation for further joint treatment.

ACTIVATED SLUDGE

It was anticipated that treatment of egg breaking wastewaters with the activated sludge process would be difficult because of the high strength of the wastes. In order to achieve an acceptable organic mass loading it was necessary to maintain the hydraulic detention period (HRT) longer than four days. The data shown in Figures 35 and 36 indicate

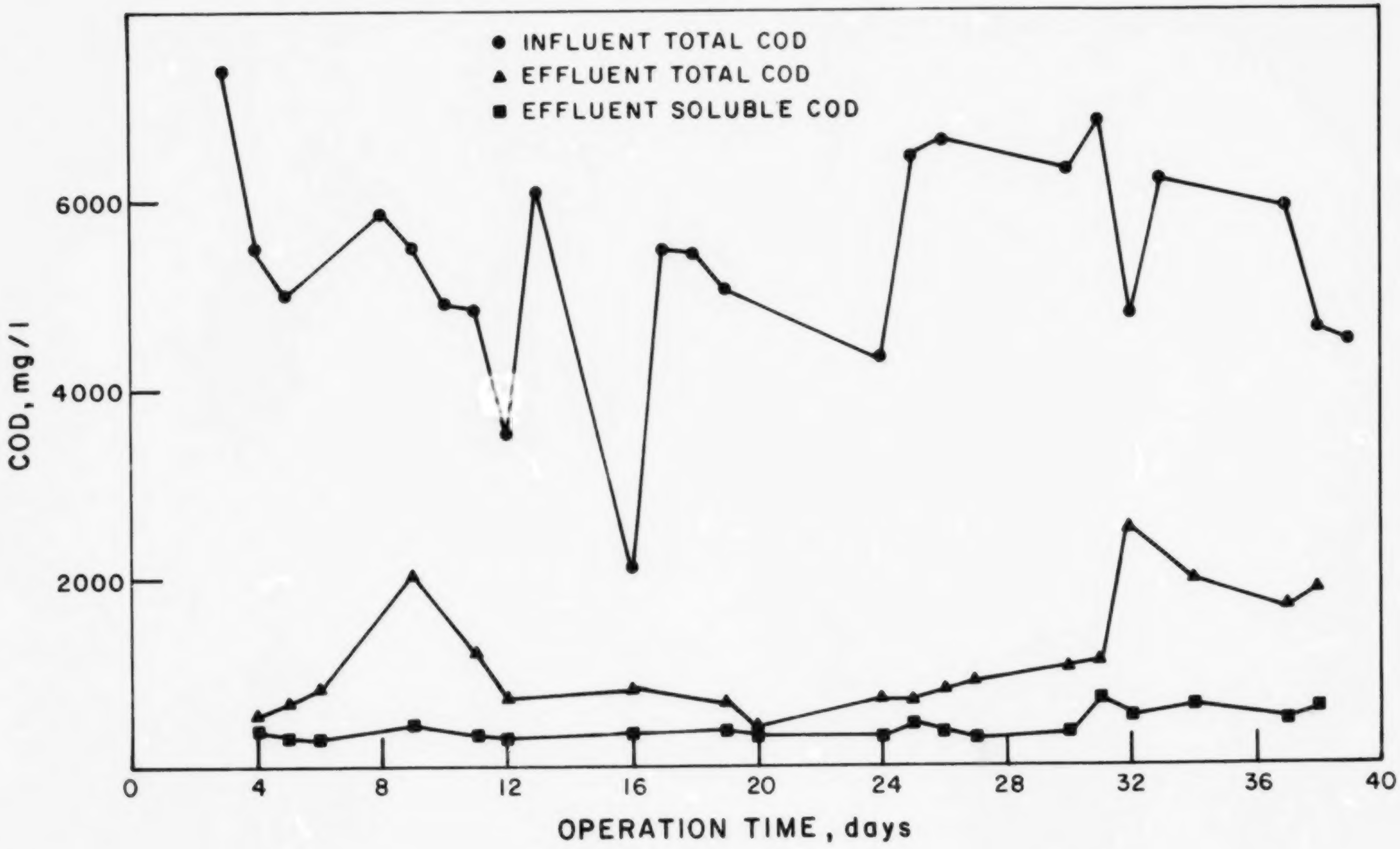

FIGURE 35. Activated sludge treatment of wastewaters from Plant B at 20°C, HRT = 4 days, SRT = 4 days.

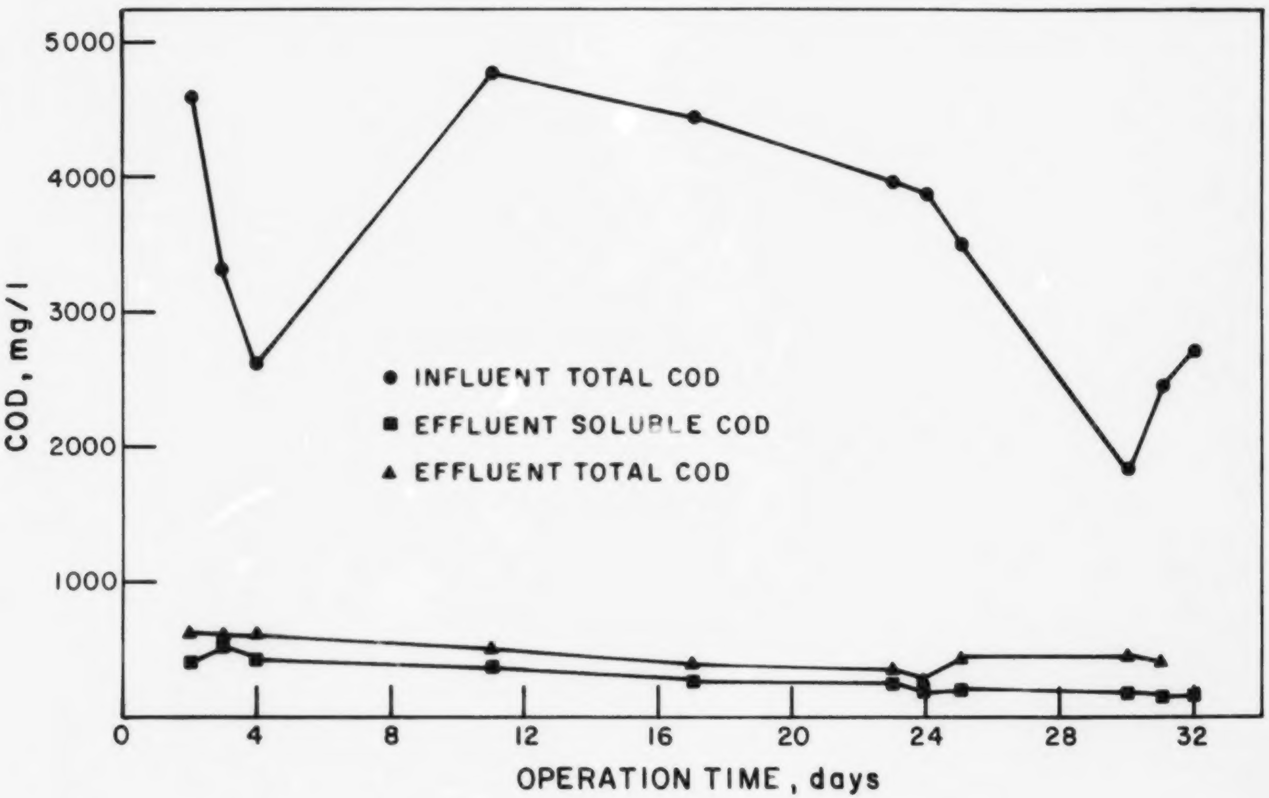

FIGURE 36. Activated sludge treatment of wastewaters from Plant B at 20°C, HRT = 4 days, SRT = 10 days.

that the effluent quality was similar to the effluent from the aerated lagoons.

Table 27 summarizes all results from activated sludge treatment of wastes from Plants A and B. Table 27 shows that pH values were observed to be in a range of 7.0-7.6 and alkalinity was not limiting the conversion of ammonia nitrogen to nitrate nitrogen. Nitrate concentrations of 32.8 mg/ℓ were experienced at an SRT of four days in one instance and approximately 2 mg/ℓ at an SRT of 4 days using wastes from Plant A. This seems to indicate that an SRT of 4 days may be the lower limit at which efficient nitrification occurs.

The sludge in these units settled poorly and the high effluent turbidities indicated that this process would be a poor choice for the treatment of egg breaking wastes.

Data accumulated from the bench scale operations were arranged in such a manner as to produce yield, endogenous respiration and oxygen utilization coefficients. Yield coefficients were 0.245 and 0.300 mg cells per mg COD removed (soluble COD basis), endogenous respiration coefficients were determined to be 0.060 and 0.043 day^{-1}, and oxygen use coefficients were 0.583 for a' and 0.164 day^{-1} for b'.

The activated sludge process is capable of producing an effluent suitable for discharge to a joint treatment system without resulting in a surcharge for excessive oxygen demand or suspended solids. However, problems with settleability of the sludge should be anticipated with this system.

ROTATING BIOLOGICAL CONTACTOR

A final aerobic treatment process investigated was the rotating biological contactor (RBC). All of the previous treatment schemes involved

Table 27. CHARACTERISTICS OF ACTIVATED SLUDGE TREATMENT OF EGG PROCESSING WASTEWATERS AT 20°C (All quantities in mg/ℓ unless otherwise noted, mean value, $5 < n < 35$)

Parameter		Plant A		Plant B		
	SRT, θ_c (days)	10	4	10	7	4
	HRT, θ (days)	4	4	4	4	4
Influent conc.						
COD, total		5,130	4840	5970	4450	5170
TKN, total		234	198	277	197	258
Operating conditions						
pH		7.0	7.3	7.2	7.6	7.4
Alkalinity, as $CaCO_3$		46	152	200	183	193
O_2 uptake, mg O_2/ℓ/hr		18.4	-	18.0	7.2	20.1
NH_3-N		3.1	18.8	21.8	12.9	20.3
NO_2^--N		5.5	16.4	0.4	0.2	2.3
NO_3^--N		20.2	1.9	51	14	32.8
Clarified treated effluent						
SS		158	-	496	149	380
COD, total		325	-	1140	344	1140
COD, soluble		101	914	401	140	441
TKN, total		27	-	105	46	69
Turbidity, JTU		-	-	100	78	102
Removal eff., %						
COD, total		94	-	81	92	78
COD, soluble		98	81	93	96	91
TKN, total		88	-	62	76	73

suspended growth systems whereas the RBC is an adhered growth treatment unit. This system is similar to the previous processes in that excess solids are produced by the oxidation of the substrate and have to be removed from the effluent.

Figure 37 contains the results from RBC treatment at a hydraulic retention period of nearly two days and Table 28 summarizes the results obtained with this process. The pH of the effluent varied from 7.2-7.7 without any deficits in total alkalinity. A surprising result was that nitrification was at least 50 percent efficient at high loading rates even though the effluent COD exceeded several hundred mg/ℓ. Regardless of the loading rates used (1.4-7.3 lb COD/1000 ft^2) there was always a dissolved oxygen level in all of the four RBC cells.

The RBC units are capable of producing effluents suitable for further treatment without surcharge payments to minicipalities and at low loadings can produce effluents with turbidities less than 27 JTU. Pretreatment using RBC units can be accomplished at low loading rates, $<$ 3 lb COD/1000 ft^2-day. The question that must be answered for a particular egg processing plant is whether the capital cost for equipment and operating costs for power, maintenance and sludge handling are less than surcharges encountered if no treatment was applied.

ANAEROBIC-AEROBIC SERIES TREATMENT

When it was observed that the activated sludge process and aerated lagoons were continuously producing effluent with high turbidity, dispersed biological flocs and residual color, additional alternatives needed to be developed in order to provide higher quality effluents. The thought of operating an anaerobic process initially brought to mind production of obnoxious odors, namely hydrogen sulfide or "rotten egg" odors. Contrary to this assumption, anaerobic lagoons operated in this study did not produce highly objectionable odors. However,

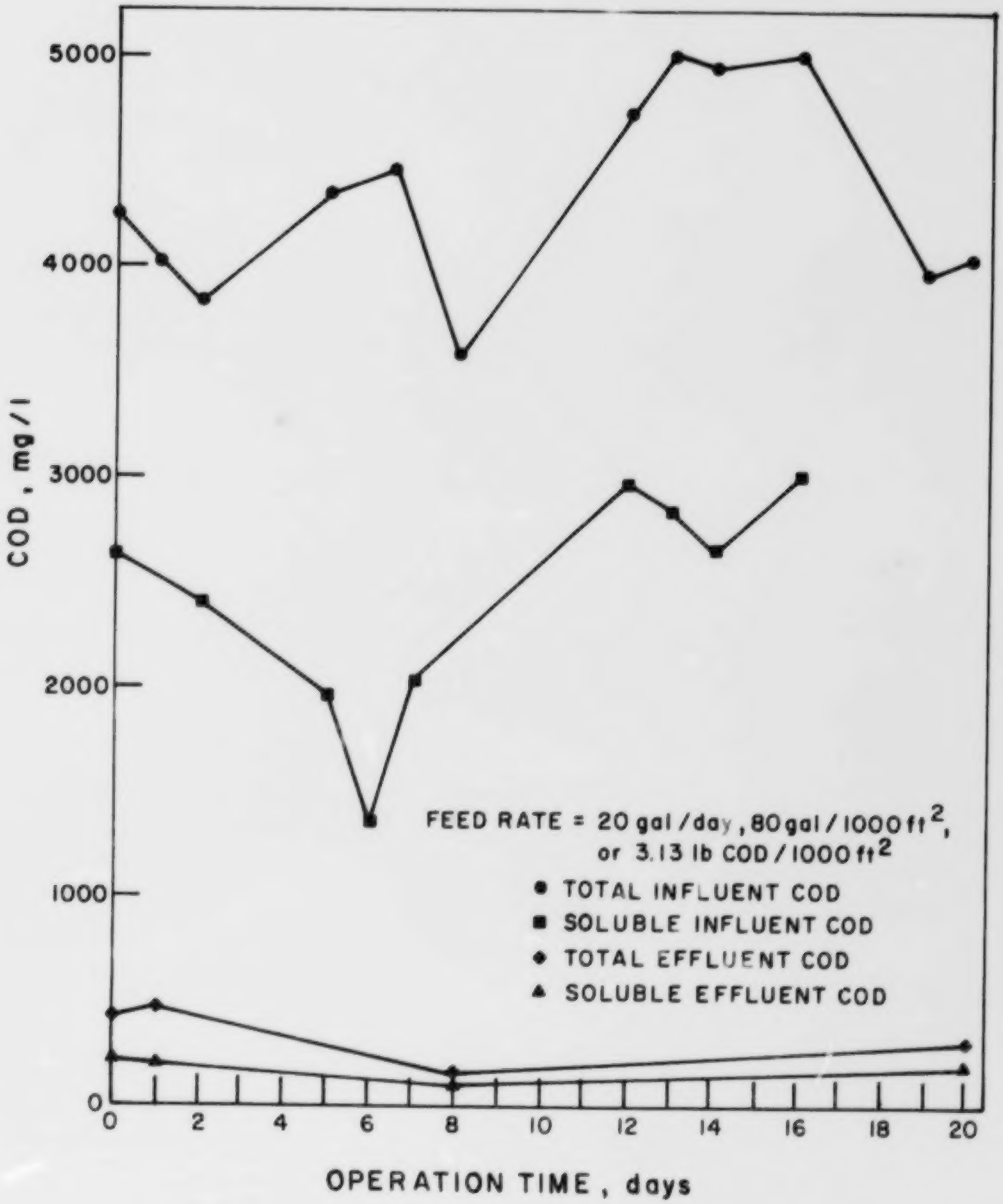

FIGURE 37. RBC treatment characteristics with wastewaters from Plant B.

Table 28. ROTATING BIOLOGICAL CONTACTOR TREATMENT CHARACTERISTICS WHEN APPLIED TO EGG BREAKING WASTES FROM PLANT B (Operating temperatures were 21 to 24°C - all units in mg/ℓ unless otherwise noted, mean value $5 < n < 20$)

Parameter		RBC Loading Rates		
	Volumetric (gal/1000 ft^2-day)	40	80	160
	Organic (lb COD/1000 ft^2-day)	1.38	3.13	7.32
	HRT, days	3.6	1.8	1.2
Influent characteristics				
COD, total		4,150	4,690	5,490
TKN, total		225	182	262
Clarified effluent characteristics				
COD, total		320	350	760
COD, soluble		200	170	240
SS		45	104	304
pH		7.7	7.2	7.2
Alkalinity as $CaCO_3$		365	301	657
D.O.		7.8	6.4	4.1
TKN, total		29.7	54.5	63.8
NH_3-N		1.5	16.3	17.0
NO_2^--N		1.9	4.1	42.5
NO_3^--N		11.5	3.4	60
JTU		27	56	86
Observed sludge production, mg solids produced in clarified effluent per mg COD removed		0.123	0.149	0.035
Removal efficiency, %				
COD, total		92.3	92.5	86.1
COD, soluble		95.1	96.3	95.7
TKN, total		86.8	70.0	75.6

anaerobic lagoons by themselves would not be acceptable because of the oxygen demand associated with the discharge of wastes from anaerobic processes. Thus all anaerobic lagoons were followed in series with aerobic lagoons operating at a six day detention period. Another concern with the anaerobic processes was that low temperatures would cause depressed removal efficiencies. Thus comparative studies were conducted at 20°C and 10°C.

A total of six anaerobic lagoons followed by aeration chambers were examined. Four of the lagoons were operated at 20°C and two at 10°C in order to determine temperature effect on removals and solids accumulation.

The data illustrated in Figures 38, 39 and 40 are representative of the surprising capabilities of this combination system. Data for all units are summarized in Table 29. All soluble COD removal efficiencies exceeded 98 percent and system number 6 (Table 29) with a 5-cell anaerobic unit was most efficient. A 5-cell anaerobic lagoon and a 1-cell anaerobic lagoon both operated at 20°C and a HRT of 10 days resulted in similar reductions in TKN, but the total COD removal in the 5-cell anaerobic lagoon was 91.4% and the single cell system was 81.7% efficient.

Similar graphical analysis for substrate removal coefficient, K, was conducted for the anaerobic lagoons as for the aerobic lagoons shown in Figure 24. The 20°C anaerobic lagoon K was found to be 0.63 day^{-1}. This was very similar to the removal coefficients obtained for the aerobic lagoon treatment of wastes from Plants A and B (0.76 and 0.58 day^{-1}, respectively). This procedure was not applicable to the lower temperature anaerobic lagoons and the aerated lagoons because the lack of difference between the characteristics of the units studied. However, the observed efficiencies at 10 and 20 day hydraulic retention periods at 10°C were similar to that observed at 20°C even though the effluent was 50 percent less at this higher temperature. Whereas the 20°C ten day HRT anaerobic lagoon removed 82 percent of the total COD, the removal efficiency in the same lagoon at 10°C was 77 percent efficient.

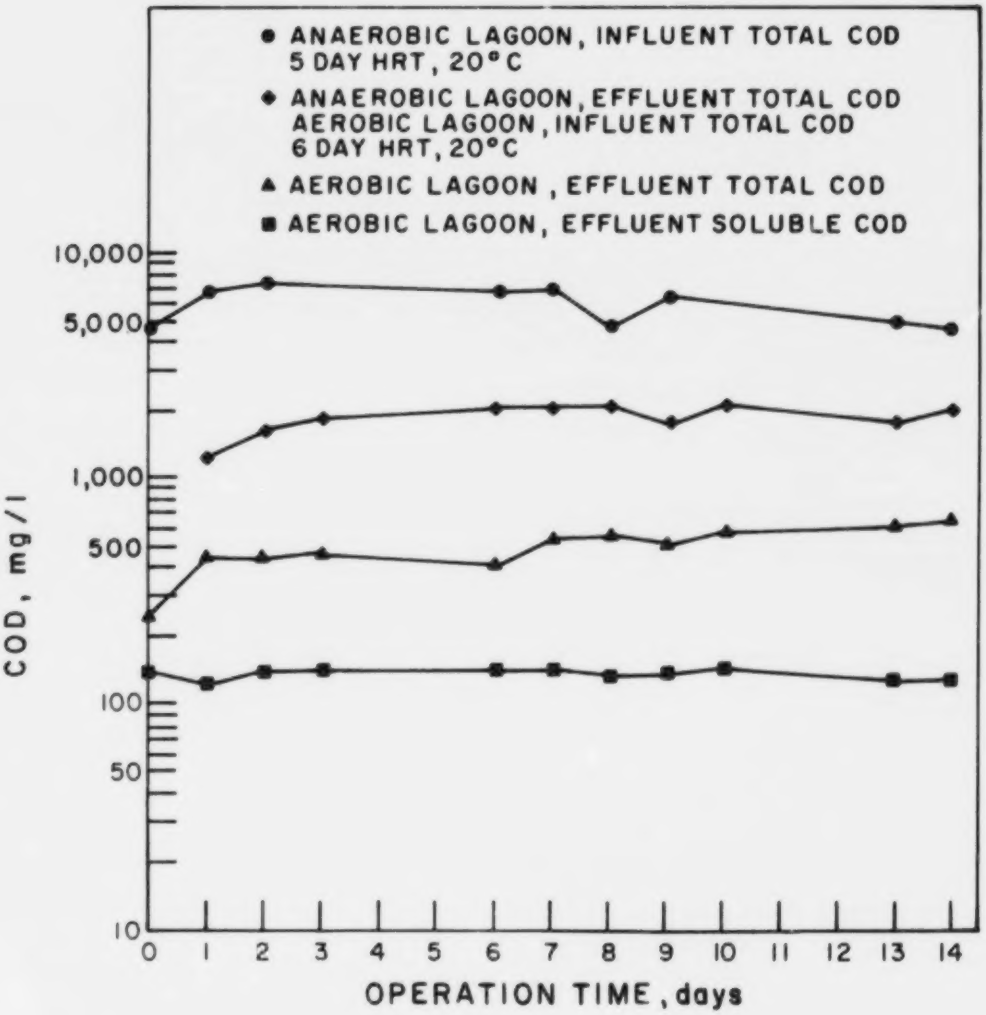

FIGURE 38. Series lagoon treatment with 5 day HRT in the first anaerobic lagoon at 20°C and 6 day HRT in the aerobic lagoon at 20°C.

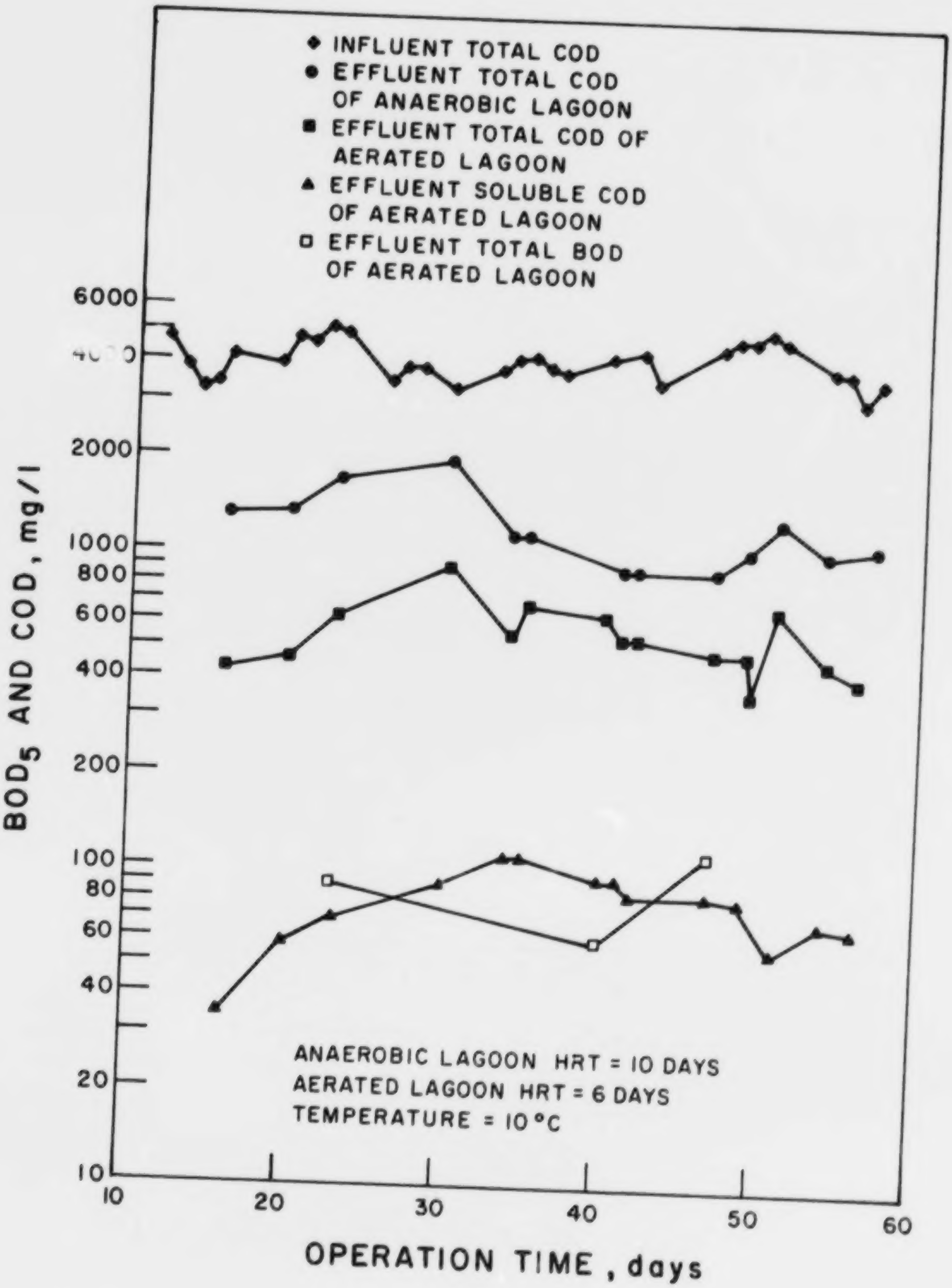

FIGURE 39. Series lagoon treatment with 10 day HRT at 10°C in the first anaerobic lagoon and 6 day HRT at 10°C in the aerobic lagoon.

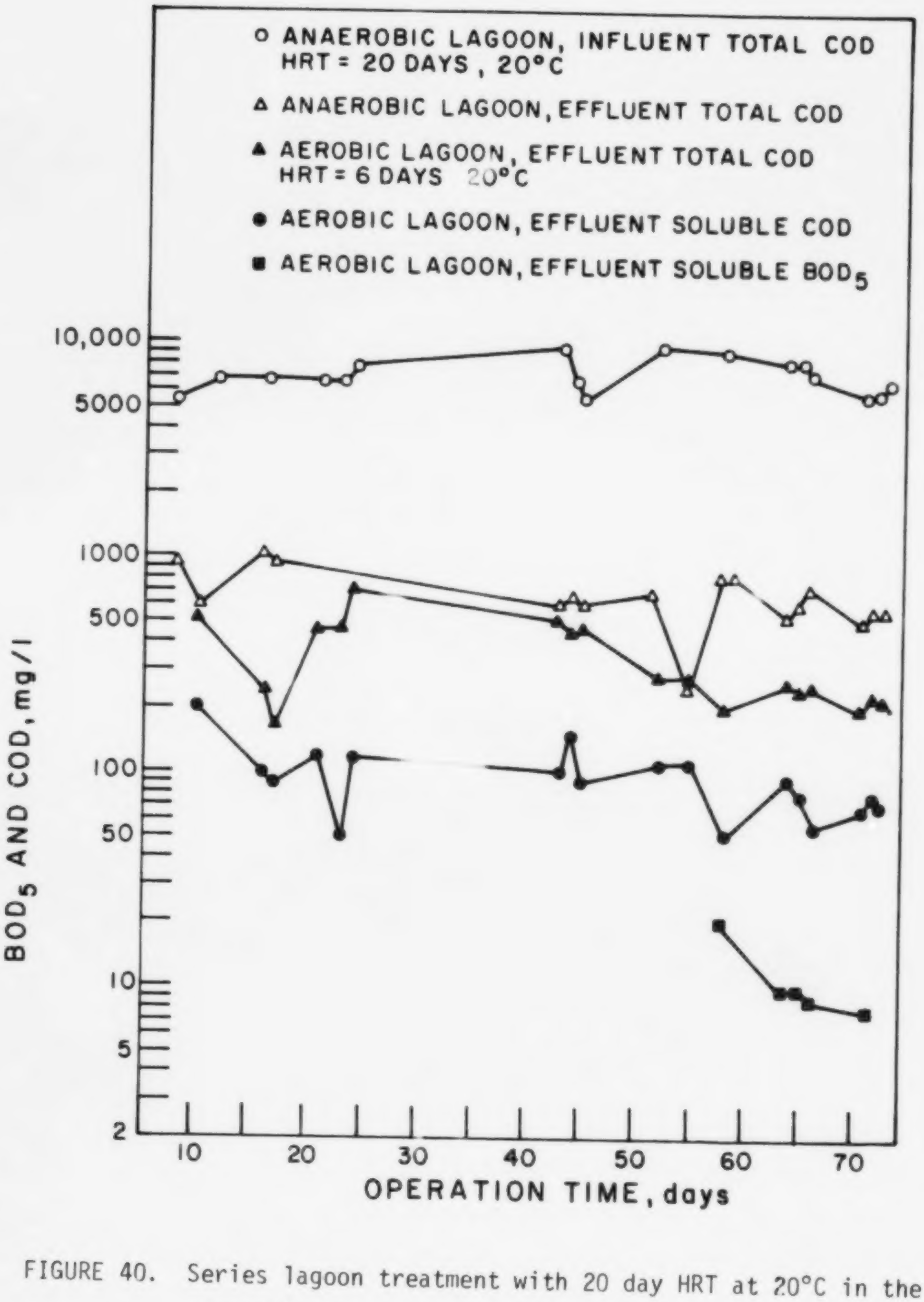

FIGURE 40. Series lagoon treatment with 20 day HRT at 20°C in the first anaerobic lagoon and 6 day HRT at 20°C in the aerobic lagoon.

Table 29. TREATMENT OF EGG BREAKING WASTEWATERS USING SERIES TREATMENT OF ANAEROBIC LAGOONS FOLLOWED BY AEROBIC LAGOONS (All aerobic lagoons have an HRT of 6 days - all quantities in mg/ℓ unless otherwise noted, mean value 5 < n < 31)

Parameters	System 1		System 2		System 3	
	Anaerobic	Aerobic	Anaerobic	Aerobic	Anaerobic	Aerobic
Temperature, °C	20		10		20	
HRT, days	20	6	20	6	10	6
Influent COD, total	7020	590	4200	940	4900	896
Effluent COD,						
total	590	-	944	-	896	-
soluble	-	90	-	66	-	72
Organic loading rate, lb COD/1000 ft^2-day	22	-	13	-	31	-
Effluent turbidity, JTU	-	4.8	-	9.1	-	-
Soluble COD removal efficiency, %						
unit	91.6	84.7	77.5	93.0	81.7	92.0
system	98.7		98.4		98.5	
Influent TKN, total	328	165	221	164	230	187
Effluent TKN, total	165	35	164	105	187	38
TKN removal efficiency, %						
unit	42	79	26	36	19	80
system	89.3		52.5		83.5	

Table 29. (continued) TREATMENT OF EGG BREAKING WASTEWATERS SERIES TREATMENT OF ANAEROBIC LAGOONS FOLLOWED BY AEROBIC LAGOONS (All aerobic lagoons have an HRT of 6 days - all quantities in mg/ℓ unless otherwise noted, mean value $5 < n < 31$)

Parameters	System 4 Anaerobic	- Aerobic	System 5 Anaerobic	- Aerobic	System 6 Anaerobic	- Aerobic (5 cells)
Temperature, °C	10		20		20	
HRT, days	10	6	5	6	10	6
Influent COD, total	4500	1050	5430	1970	4600	395
Effluent COD,						
total	1050	-	1970	-	395	-
soluble	-	86	-	72	-	48
Organic loading rate lb COD/1000 ft^2-day	29	-	68	-	29	-
Effluent turbidity, JTU	-	21.4	-	-	-	5.8
Soluble COD removal efficiency, %						
unit	77.1	91.8	63.7	96.3	91.4	87.8
system	98.1		98.7		98.9	
Influent TKN, total	209	157	287	267	220	183
Effluent TKN, total	157	147	267	58	183	70
TKN removal efficiency, %						
unit	25	6.4	8.7	78	16.8	96.2
system	29.7		80.0		96.8	

Thus it can be concluded that there was little effect on the substrate removal coefficient between 10°C and 20°C. The greatest difference occurred in the loss of nitrification activity at 10°C.

Perhaps the most impressive characteristics of the combination anaerobic-aerobic lagoon system was the high clarity and highly flocculated nature of suspended materials in the effluent from the aerated unit. In no case did the total effluent turbidity exceed 10 JTU for units operated at 20°C and 10°C. Since all solids settled rapidly the soluble BOD_5 values shown in Figure 40 of about 10 mg/ℓ are indicative of the efficiency that this treatment combination is capable of achieving with an influent COD varying between 5,000 and 10,000 mg/ℓ and a total system hydraulic detention period of 26 days.

Detailed summary of influent and effluent characteristics for single-cell series lagoon systems are given in Tables 30 and 31.

MULTI-CELL VERSUS SINGLE CELL SYSTEMS

Egg wastewaters are highly biodegradable and for this reason can be treated by various combinations of systems. Utilization of multi-cell units enable the use of smaller systems to achieve the same treatment efficiency. Data supporting this statement are illustrated in Figure 41 Total COD removal with a one-cell aerated lagoon at ten day HRT achieved 60 percent removal efficiency, whereas a five-cell aerobic lagoon with the same overall HRT achieved a removal efficiency of 83.5 percent, and a five-cell anaerobic unit with a ten day HRT obtained a removal efficiency of 91 percent. The soluble COD removal efficiency in a five-cell unit aerobic lagoon with a system HRT of six days was equivalent to that obtained in a one-cell unit at about thirty days HRT. Thus these data indicate that compartmentilization of lagoons treating egg breaking wastes will improve the efficiency for any given volume. However, to protect the system against shock loads it is suggested that no more than three cells be used for any lagoon.

Table 30. INFLUENT AND EFFLUENT CHARACTERISTICS OF SINGLE CELL ANAEROBIC LAGOONS FOLLOWED BY AEROBIC LAGOONS WITH HRT OF 6 DAYS AT 20°C (All units in mg/ℓ unless otherwise noted, mean value $5 < n < 31$)

Parameter	Influent HRT, days			Effluent HRT, days			Effluent from aerobic lagoons following anaerobic lagoons with HRT, days		
	5	10	20	5	10	20	5	10	20
COD total	4300	4900	2020	1970	900	590	680	410	300
COD soluble	-	-	-	-	-	-	72	72	90
BOD total	-	-	-	-	-	-	-	-	370
BOD soluble	-	-	-	-	-	-	-	-	13
Suspended solids	-	-	-	-	-	-	4.5	320	220
pH	-	-	-	6.9	7.1	7.2	7.2	7.0	7.3
Total alkalinity as $CaCO_3$	-	-	-	135	810	720	75	60	160
TKN	290	230	320	260	190	164	58	38	35
NH_3-N	-	-	-	230	158	136	0.1	25	21
NO_2-N	-	-	-	-	-	-	6.25	15.6	22.0
NO_3-N	-	-	-	-	-	-	108.3	109.3	91.9
O_2 uptake	-	-	-	-	-	-	18.0	10.3	5.2
Turbidity JTU after 2 hours settling	-	-	-	-	-	-	-	-	4.8

Table 31. INFLUENT AND EFFLUENT CHARACTERISTICS OF SINGLE CELL ANAEROBIC LAGOONS FOLLOWED BY AEROBIC LAGOONS WITH HRT OF 6 DAYS AT 10°C (All units in mg/ℓ unless otherwise noted, average value $6 < n < 15$)

Parameter	Influent HRT, days		Effluent HRT, days		Effluent from aerobic lagoons following anaerobic lagoons with HRT, days	
	10	20	10	20	10	20
COD total	4580	4200	1050	944	574	585
COD soluble	2400	2500	-	-	86	66
BOD total	-	-	-	470	-	220
BOD soluble	-	-	-	-	-	29
Suspended solids	730	670	-	-	355	308
pH	-	-	7.5	7.4	8.6	7.7
Alkalinity as $CaCO_3$	-	-	620	662	553	222
TKN	208	221	157	164	147	104
NH_3-N	-	-	105	133	78.1	37.9
NO_2-N	-	-	-	-	0.1	1.5
NO_3-N	-	-	-	-	0.2	49.8
O_2 uptake	-	-	-	-	7.0	6.9
Turbidity JTU after 2 hours settling	-	-	-	-	21.4	9.1

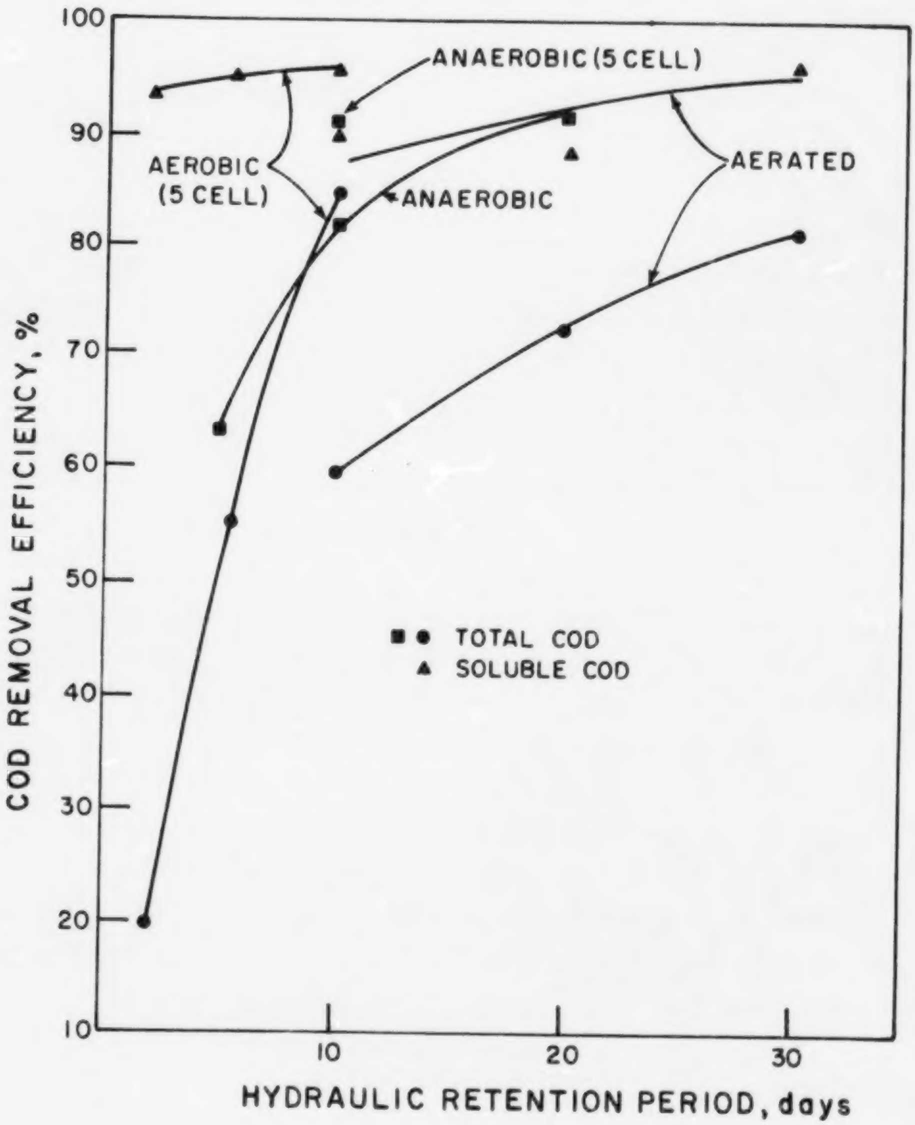

FIGURE 41. Comparison of multi-cell and single cell aerobic and anaerobic treatment processes at 20°C.

Detailed summary of analysis for the multiple cell anaerobic-aerobic system is shown in Table 32. All values in this table are averages of six days of steady state operation.

LAGOON SLUDGE ACCUMULATION

Most lagoon treatment systems do not have sludge collection or handling components. However, operation of these units on egg breaking wastewater raised several questions. The high clarity and low solids concentrations in effluents of the system indicated that most of the solids entering the system were biodegradable. Although all units were completely mixed at least once daily, the wasting procedure with the anaerobic lagoons was conducted before mixing in order to more closely approximate actual field conditions. Wasting took place from a submerged tube midway between the floating scum layer and the sludge on the bottom. It also appeared that the egg wastes and the anaerobic system acted as an efficient bio-precipitation unit. Thus, it was important to estimate the rate of sludge accumulation that might occur. Also, because of the rapid settling nature of the SS in the effluent from the secondary aerobic lagoon it was felt a liquid solids separation step would clarify the effluent.

A typical rate of accumulation of solids in anaerobic lagoons is shown in Figure 42. This data indicates that the rate of solids accumulation in the first unit of the series treatment system is small at temperatures of 20°C, but increases significantly at lower temperatures. Further studies are needed to determine the net yield over long periods when the temperature varies significantly. Data for all anaerobic lagoons is summarized in Table 33. It is interesting to note that the longer the retention period and the higher the temperature, the lower the sludge accumulation rate. Long term storage of sludge in this unit at temperatures around 20°C would probably result in a low rate of sludge accumulation.

Table 32. INFLUENT AND EFFLUENT CHARACTERISTICS OF A 5-CELL 2 DAY HRT PER CELL ANAEROBIC LAGOON FOLLOWED BY AN AEROBIC LAGOON WITH A 6 DAY HRT AT 20°C (average value $10 < n < 15$)

	Influent to 5-cell Anaerobic Lagoon	Effluent from 5-cell anaerobic lagoon & influent to aeration chamber	Effluent from aeration chamber following anaerobic lagoon
COD, total	4604	395	177
COD, soluble	2725	120	48.2
Suspended solids	721	-	177
pH	-	7.9	6.5
Total alkalinity, $CaCO_3$	-	885	37
TKN (mg/ℓ)	220	183	7.0
NH_3-N (mg/ℓ)	-	153	4.1
NO_2^--N (mg/ℓ)	-	-	6.0
NO_3^--N (mg/ℓ)	-	-	133
O_2 uptake (mg/ℓ/hr)	-	-	8.9
Turbidity (JTU)	-	-	5.8

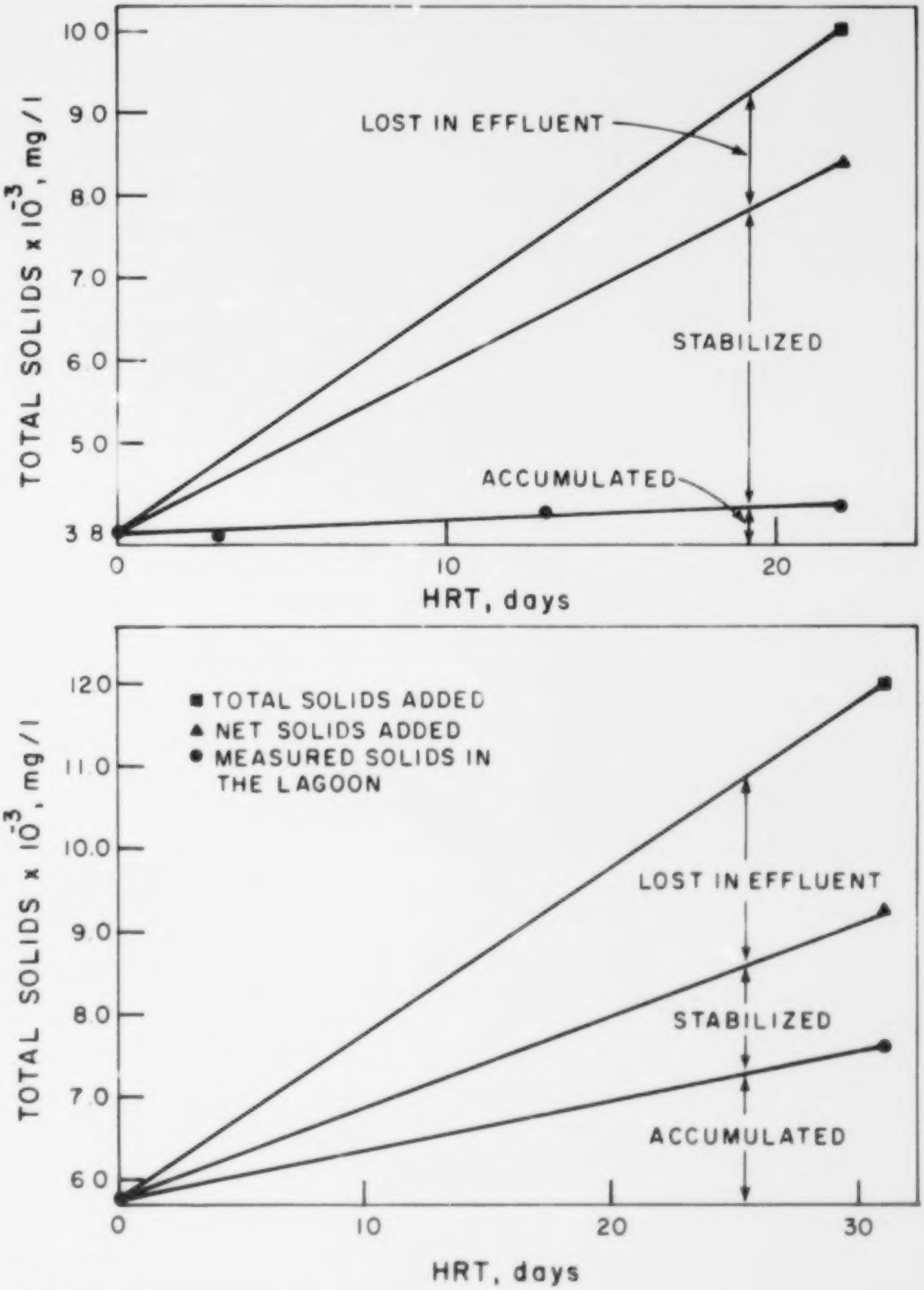

FIGURE 42. Comparison of the fate of solids in anaerobic lagoons with 10 day HRT at 20°C (top) and 10°C (bottom).

The sludge accumulation is less in the aerobic lagoon than in the anaerobic process. The measured volume of sludge that accumulates is shown in Table 34, expressed as a fraction of the total volume of wastewaters treated. The accumulation rate was about 2 percent of the flow in most instances.

Table 33. MEASURED SLUDGE SOLIDS ACCUMULATION RATE IN ANAEROBIC LAGOONS

Anaerobic lagoon operating conditions		Solids accumulation rate
HRT (days)	Temp (°C)	% of total solids added per day
10	10	30
20	10	68
5	20	12
10	20	6.0
20	20	5.4

Table 34. MEASURED SLUDGE VOLUME ACCUMULATION RATE IN EFFLUENTS FROM 6 DAY HRT AEROBIC LAGOONS FOLLOWING ANAEROBIC LAGOONS

Pretreatment anaerobic lagoons		aerobic lagoon	Sludge volume accumulated
HRT (days)	Temp (°C)	Temp (°C)	(% total volume treated)
10	10	10	1.7
20	10	10	3.7
20	20	20	2.7
10 (5-cell)	20	20	1.2

Although the sludge accumulation data shown in Tables 33 and 34 are highly empirical they serve to indicate the relative magnitude of sludge storage volume required. Further studies need to be conducted to evaluate the design parameters for liquid-solids separation and sludge disposal systems.

SECTION V

DISCUSSION

This treatability study encompassed a variety of aerobic and combination anaerobic bench scale treatability units. It is evident that the high degree of treatment of egg processing wastewaters for the purpose of direct discharge to surface waters can be achieved most easily by the combination anaerobic-aerobic lagoon treatment. Anaerobic-aerobic lagoons are advantageous from the standpoint of low maintenance requirements, energy requirements and capital costs. Treatability studies have shown that the two-lagoon system is capable of producing an effluent of low turbidity with good solids settling characteristics and extremely low oxygen demanding substances.

The anaerobic-aerobic system is a unique system in that the sludge production of an anaerobic lagoon is less than the sludge production of a strictly aerobic system. Removal of solids from the effluent from the aerobic lagoon would result in an effluent quality which would qualify for direct discharge in most areas. The total BOD_5 would be less than 20 mg/ℓ, SS less than 20 mg/ℓ.

There are a number of design considerations involved with full scale operation of anaerobic-aerobic systems. Bench scale studies indicated that a scum layer will form on the anaerobic lagoon and retain odors associated with the system. It is not known how stable this scum layer will be under field conditions.

The alkalinity in the anaerobic lagoons treating egg wastes often had a relatively low value (200-800 mg/ℓ-$CaCO_3$). When the effluent from the anaerobic lagoon enters the aerated unit the nitrifying organisms consume bicarbonate and also release hydrogen ions in the oxidation of ammonia nitrogen to nitrate nitrogen. Experience has shown that the aerated lagoon may need additional sources of inorganic carbon.

Another possible drawback of these systems is the possible impact of low temperatures on treatment plant efficiency. At temperatures lower than 10°C, the removal capacity of this combination may be diminished even though the organic removal efficiencies were nearly the same at 20°C as they were at 10°C

The design procedure for the lagoons is simplified because of the fact that the substrate removal coefficient, K, was nearly the same for anaerobic and aerobic lagoons (0.63 day^{-1} versus 0.67 day^{-1}, respectively), and also because there appeared to be no significant effect in effluent total COD quality when the temperature was decreased from 20°C to 10°C.

A common parameter determined for most of the bench scale operations was turbidity and this measurement provided the most impressive difference between treatment systems. Figures 43 and 44 give comparisons of effluent turbidity for a variety of treatment processes. The anaerobic-aerobic systems provide an effluent quality superior to effluents of aerobic biological treatment. Aerobic treatment processes produced highly turbid effluents due to dispersed solids and a residual yellow-brown color.

Although process selection for each plant should be examined carefully, and treatability studies conducted to determine specific requirements, the combination lagoon system had a greater capacity than other systems. A system that could meet effluent BOD_5 and SS requirements of 20 mg/ℓ each is shown in Figure 45. This system would combine a 3 cell 20 day HRT anaerobic lagoon with a 3-cell 6 day HRT aerated lagoon. Only 3 cells are recommended as a comprise between the advantages of series

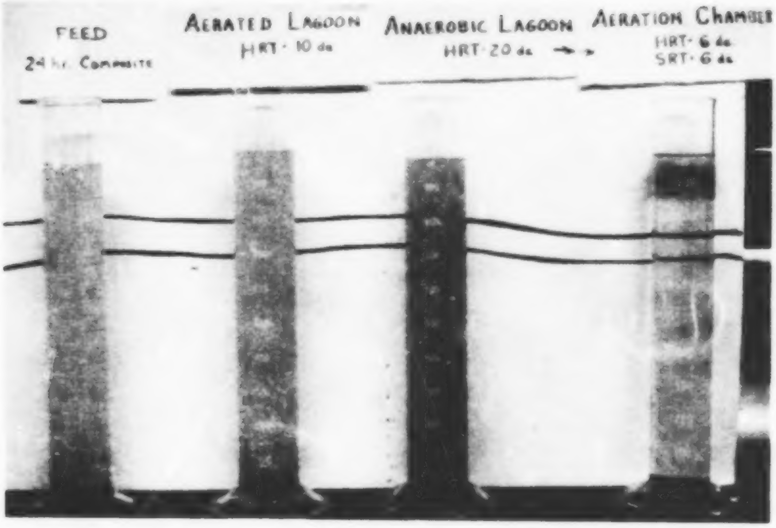

FIGURE 43. Comparison of clarity of effluents produced by various treatment processes.

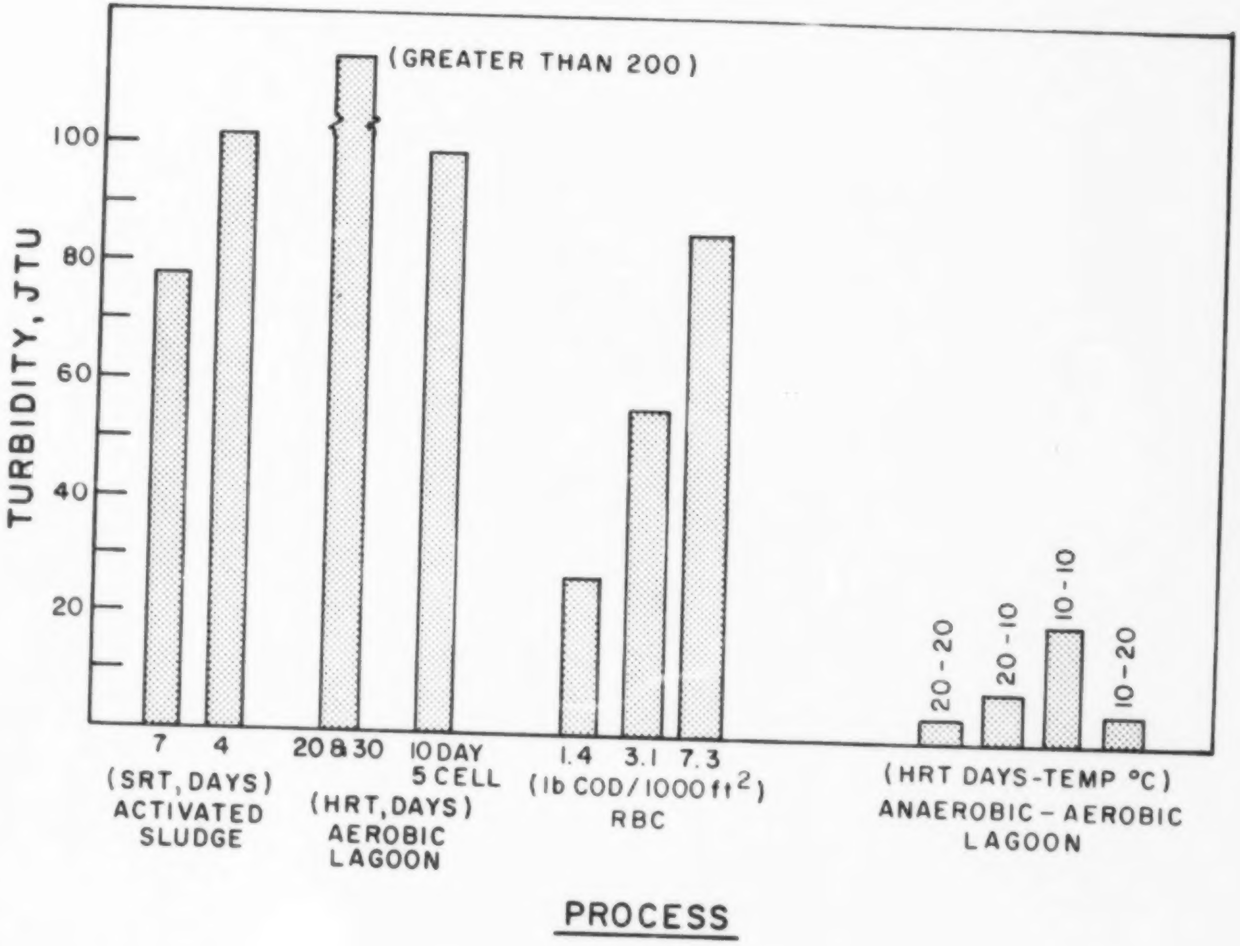

FIGURE 44. Summary of effluent turbidity from various aerobic and anaerobic-aerobic treatment systems.

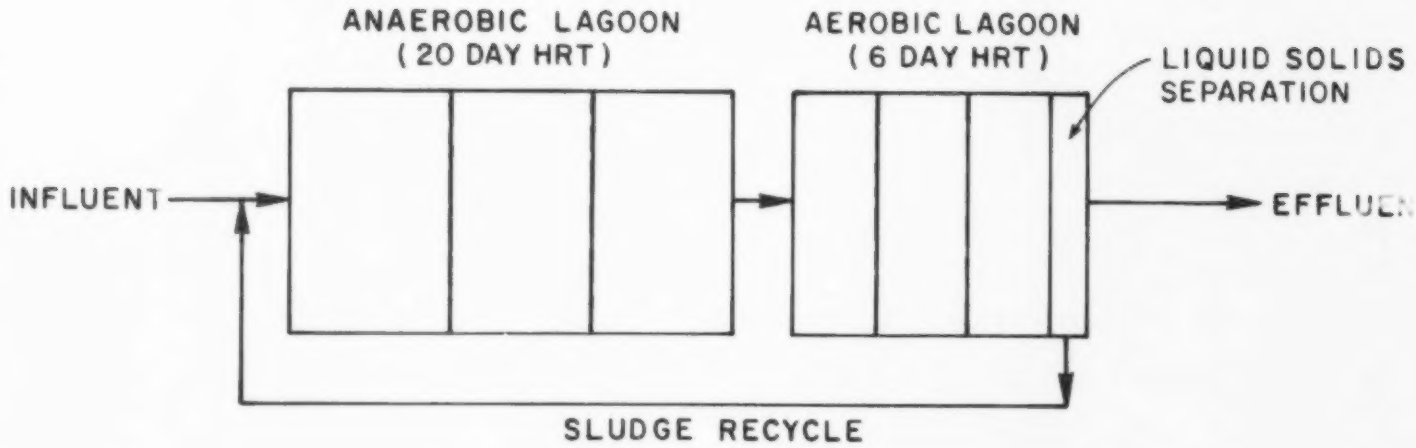

FIGURE 45. A recommended wastewater treatment system to achieve maximum organic pollution control of egg breaking wastewaters.

treatment and the impact of shock loads. The design flow would be based on the maximum production capacity projected for the months of May, June and July.

Data obtained from the treatment of egg processing wastes using aerobic treatment has shown that a HRT of 30 days for an aerated lagoon will not produce a quality effluent suitable for direct discharge to surface waters. The suspended solids settled poorly and remained at high levels in the effluents.

The activated sludge process was examined and the results indicated that the soluble COD of the effluent could be reduced to 100 mg/ℓ, but the system had faults similar to those encountered in the use of aerated lagoons. The resulting mixed liquor solids were poorly flocculated and did not settle. Suspended solids were observed to reach 400 mg/ℓ in the clarified effluent.

The RBC system provided an effluent suitable for discharge to a municipal system, but only at low organic loadings of 3 lb COD/1000 ft^2. Lower loadings may be capable of producing a high quality effluent, but 3 lb COD/1000 ft^2 is less than that used in most applications of this process. At this low loading the costs of treatment may exceed the discharge surcharge.

In an earlier portion of this report dealing with the characterization of egg processing wastewater it was shown that for plants A and B, the ratio of BOD:N:P is less than the ratio of 100:5:1 which is necessary to accomplish aerobic stabilization of wastewaters. Bench scale aerobic processes operated in this study were fed with wastes from Plants A and B and at times the phosphate concentration would approach zero thus indicating a phosphate deficiency for aerobic processes. Since the cell yield of anaerobic bacteria is less than those of aerobic organisms, the amount of phosphorus needed by anaerobic biological systems is substantially less than the BOD:N:P ratio of 100:5:1. Phosphate concentrations in the aerobic lagoons following anaerobic lagoons were determined periodically and indicated that sufficient phosphate was present to ensure complete treatment without additional phosphorus.

Due to increased environmental awareness, more environmental engineers will be faced with the design of treatment systems to handle an ever increasing population. Often times municipal systems are aerobic treatment processes, and if an industry such as an egg breaking plant discharges to this particular plant, there may be difficulty in meeting regulatory effluent guidelines. Experience from this study indicated that poor effluent quality can be expected when treating egg processing wastes aerobically. Thus complaints from operators of municipal aerobic plants will often occur when egg breaking plants contribute sizeable portions of the total organic loading. In the town where plant E is located, there does not seem to be a problem with the operation of the municipal trickling filter, but the egg processing wastes constitute less than 10 percent of the municipality's organic loading.

PART IV

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PART V

GLOSSARY

TERMS

Breaking - refers to the physical separation of the inner contents of shell eggs from the shell and shell membranes by machine or by hand.

Breaking plant - a plant in which shell eggs are broken, pasteurized and otherwise prepared for the production of liquid and frozen and/or egg solids.

Breaking stock - shell eggs used for breaking.

Case of eggs - usually refers to a standard egg case holding 30 dozen eggs. There are egg cases on the market that hold 24 and 28 dozen eggs. The "U.S. Weight Classes For Consumer Grades for Shell Eggs" are given below (6).

Size or Wght. Class	Min. net wght per doz. (oz.)	(lbs.)	Min. net wght. per 30 doz. (lbs.)	Min. wght. for indiv. eggs @ rate per doz. (oz.)
Jumbo	30	1.87	56	29
Extra Large	27	1.69	50 1/2	26
Large	24	1.50	45	23
Medium	21	1.31	39 1/2	20
Small	18	1.13	34	17
Peewee	15	0.94	28	--

Checks - an individual egg that has a broken shell or crack in the shell with its shell membranes intact and its contents do not leak.

Egg (or shell egg) - means the shell egg of the domesticated chicken, turkey, duck, goose or guinea (12). (In this publication "egg" usually refers to an egg from a chicken.)

Egg meats - the content of a shell egg including the yolk and the albumen but excluding the shell membranes and the shell (4).

Egg or shell egg processing plant - usually refers to a plant where shell eggs are washed, graded for size and quality and packed.

Egg products - whole eggs, whole egg blends, whites and yolks in liquid and/or frozen or dried form (4) (13).

Egg Products Inspection Act - a federal law providing for the mandatory inspection of certain egg products, restrictions of certain qualities of the eggs, and uniformity of standards for eggs and otherwise regulate the processing and distribution of eggs and egg products, etc. (12).

Egg solids - a term used synononomously with dried eggs. There are many types but the most common are whole eggs, albumen, whole egg blends and yolk solids (4).

Emulsion - an oily mass in suspension in a watery liquid. For example, salad oil is an emulsion of egg yolks mixed with water, starch, vegetable oils and spices (4).

Frozen whole eggs - a mixture of whites and yolks in natural proportions, as broken, with no additives, which have been frozen solids. There are also *frozen whites*, *frozen plain yolks*, *frozen sugared yolks*, etc. (13).

Integration or coordination - may be generally defined as the tying together of firms and/or functions through contracts, agreements or ownership.

Leakers - an individual egg that has a break in the shell and shell membranes to the extent the egg contents are exuding or free to exude through the shell (53).

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Official plant - refers to any plant as determined by the Secretary of Agriculture (U.S.) or the Administrator of the Consumer and Marketing Service (U.S.D.A.) where inspection and/or grading service is maintained or conducted by the U.S. Department of Agriculture (12) (53).

Pasteurize - means to subject egg products to heat or other treatments to destroy harmful, viable microorganisms by such processes as might be described by the regulations of the Egg Products Inspection Act (12).

Poultry - domesticated chickens, turkeys, ducks, geese or guineas.

APPENDIX A

SUMMARY OF HISTORICAL AND TECHNOLOGICAL DEVELOPMENTS AND THEIR RELATION TO OPERATING PROBLEMS

SHELL EGG INDUSTRY

Marketing

1800 to 1850	History shows a primitive beginning in the 1800's. Eggs were used as gifts to friends or barter at the general store. References to egg weights and size of air cells were made.
1850	Eggs were packed with small end down.
1859	An article in "Curiosities of Food" by P.L. Simmonds noted the novelty of candling eggs in New York City.
1862	Grades were quoted in 1862, but only by areas of origin.
1875	The Butter and Cheese Exchange was enlarged to cover the needs of egg merchants. The Pet-Stock, Pigeon and Poultry Bulletin indicated in May 1875 a grading system classifying eggs as Extras, Firsts, and Thirds.
1878	The American Poultry Yard discussed egg flavor.
1900 to 1925	Frank G. Urner, editor of American Creamery and Poultry Produce Review worked for conformity of commercial grading system. L.B. Kilbourne of the National Poultry, Butter and Egg Association set up meetings to develop standards.
1922	The Capper-Volstead Act provided a temporary delay in the adoption of national standards.
1923	First draft of proposed standards was written. It was adopted in 1925.
1932	An "Approved Buying Grades for Eggs" was adopted in the midwest.

1934	The U.S.D.A. issued official standards with legal status in February 1934. A pictorial chart was developed showing variation in quality of fresh laid eggs.
1937	The Hough unit for measuring the height of albumen was established.
1939	Federal standards were revised giving letter designations to grades.
1941 to 1945	The Armed Forces created new procurement grades during World War II.
1956	Harry E. Drews of San Diego Cooperative assembled the first underlight candling equipment.
1959	The U.S. Fresh Fancy Quality grade was adopted.
1960's	Bulk or mass candling became common in the 1960's. Government agencies began emphasizing the significance of salmonella organisms in eggs and egg products. Studies were carried out at Iowa State University showing the effects of clean versus soiled packaging materials.
1970	Congress passed the Egg Products Inspection Act in December.
1972	The shell egg part of the Act went into effect in July. The Act was amended in November to provide a classification of "nest run eggs."

Egg washing

1898	The New York Produce Review noted that packers were washing dirty eggs.
1933	Almquist designed a test to detect the cleaning of eggs by abrasives and by washing.
1945	Hand methods were used to wash eggs until some earlier models of egg washing machines were introduced near the end of World War II.

1949	The U.S.D.A. studied washing and storage of dirty shell eggs. Dr. Forsythe of Iowa State University predicted all eggs would be washed in all channels of trade.
1950's	F.B. Wright of Cornell University developed one of the first acceptable automatic egg cleaners in the 1950's.
1960's	A broad research program by Brant and Associates resolved the fundamental requirements for safe egg washing.

Packaging

1800's	The early container for eggs was the keg containing 70 dozen eggs packed in oats, straw or similar materials. Eggs were repacked into wooden boxes holding 40 dozen eggs without packing material and delivered to stores.
1870's	Sawn wood (30 and 36 dozen) egg cases came into common use.
1873	W. Weiss of the Central Fibre Products Company patented an egg case filler with a lock-strip that would secure the eggs in individual protective cells.
Early 1900's	The 30 dozen case became more popular because it was easier to handle and just about as economical as the larger case. Egg cases made from veneer wood began appearing on the market. Simple strawboard fillers and flats were used to hold the eggs in the case.
1912	Fillers made with newsboard which were manufactured from old papers, cardboard from solid pulp, and filled pulp (utilizing reclaimed newspapers) were developed and used.
1925	The "Mapes molded pulp cup flat" was introduced. This was the most significant development in egg packaging. This flat used with the filler (1873 above), invented by Weiss, was the turning point in the handling, shipping and overall protection and storage of eggs.
	The Keyes Fibre Company made a molded pulp pad flat.

1930's	The Hartman Company of Denmark invented the first filler-flat (egg trays) using alternate layers of 20 and 30 eggs and marketed them in Europe.
1931	The Keyes Fibre Company invented a variation of the filler-flat (egg tray) and marketed this product in Canada and the United States.
1940	During World War II, wooden cases were replaced by fiber egg cases. After World War II the features of the molded pulp cup flat and filler were combined into one piece. Car Pro invented a device to automatically lift eggs from the filler-flat. Filler-flats became much more acceptable to the trade.
1950's	Plastic filler-flats were introduced.

Automation & mechanization

1900	A.J. Murdock of P.W. Kiefabor and Company in Philadelphia patented an "American Improved Testing Machine" ("multi-egg candling device").
1939	One of the first automatic graders was developed and demonstrated by Mr. Otto Niederer, Sr.
1950's	There was a continued development of equipment until the innovations in the fifties and sixties. Automatic egg washers, mass candling techniques, egg sizing devices and automatic cartoning were the major changes.
1953	The first bloodspot detector was developed and patented by the U.S.D.A.
1960	H.D. Bartlett of Pennsylvania developed one of the earliest experimental egg packers. George Page later perfected one of the first commercial applications.

EGG PRODUCTS INDUSTRY

Egg breaking operations

Late 1890's	First attempts to break and freeze eggs were made independently of each other by H.J. Keith and T.S. White.
Early 1900's	Sugar added to yolks prior to freezing to prevent gelatin (H.J. Keith).
1907	Basic and applied research undertaken on principles of sanitation and refrigeration of broken-out eggs by Dr. M.E. Pennington and staff.
1912	Invention by H.A. Perry of the egg separator which separates whites from yolks.
1926	Salt added to yolks before freezing to prevent gelatin (T.M. Rector).
1935	Development by J.M. Vansant of an impellor-type liquid egg churn.
1938	First commercial pasteurization of liquid eggs by Henningsen Brothers.
Late 1930's	Invention of the "Irish" sucker which removed remaining edible whites from shells (J.C. Irish). Improvements made by J.M. Vansant.
	Dairy-type strainer adapted to strain out pieces of shell and chalazae from liquid eggs.
1943	Invention of first commercial egg breaking machine (L. Sigler). Manufacture began in 1949-50 by the Barker Poultry Equipment Company.
1952	Invention of second commercial egg breaking machine (C.H. Willsey).
Early 1950's	Development of an automatic egg breaking machine in the early 1950's by Jay Odell and O.R. Anderson of the Seymour Packing Co.

1966	Heat pasteurization of eggs was required in U.S.D.A. inspected breaking plants.
1970	Congress passed the Egg Products Inspection Act in December.
1971	The egg products part of this Act went into effect on July 1. This required rather rigid sanitary and operational practices in breaking plants. A resident U.S.D.A. inspector has to be in each plant.

APPENDIX B

IMPORTANCE OF EGG WASHING

The value of washing eggs for egg breaking purposes should be examined in further depth. While monitoring in-plant egg washing losses it was suspected that egg washing methods could contaminate rather than clean eggs in some operations. Most eggs after an hour's run are being washed in soiled cleaning water. Since egg shells are porous it seems probable that washing methods may contaminate rather than clean some egg breaking stock.

A series of egg washing experiments were carried out in two egg breaking plants in April and May to determine microbial contamination of egg shells and egg products.

SAMPLING METHODS

1. Six eggs randomly sampled from the loading belt before egg washing machine were washed in 300 ml sterile distilled water. The washings were diluted and plated on standard plant count agar according to the Standard Methods.
2. Six eggs randomly sampled from the belt after being machine washed were washed in 300 ml sterile distilled water. The washings were used as above at start up and at shut down 4 hours later.
3. Six eggs randomly sampled from the belt after chlorine sprayed were washed in 300 ml sterile distilled water and the washings were processed as above (1 and 2) at hourly intervals.
4. A sample of liquid egg was taken at hourly intervals in a sterile container as soon as the liquid egg left the egg breaking machine and dilutions of the liquid eggs were processed as 1, 2 and 3 above.
5. Rinse water of egg breaking machine at start up was sampled after

the egg breaking machine was sanitized and rinsed. Samples of the rinse were processed as 1, 2, 3 and 4 above.

6. Rinse water of the egg breaking machine was sampled after 4 hours of operation when the egg breaking machine was washed. A sample of this wash water was processed as above.

7. Rinse water of the egg breaking machine was sampled after the egg breaking machine was washed, sanitized and rinsed. A sample of this rinse was processed as 1, 2, 3, 4, 5, and 6.

8. Egg washing machine wash water overflow samples were taken at hourly intervals and processed as above samples.

9. The washing solution of the egg washing machine was sampled after it had been in operation for 4 hours.

The numbers of microorganisms per ml of waste water, washings, or per gram of liquid in Plant A are given in Appendix Table 1.

Appendix Table 2 shows data from Plant B. Sampling times were different due to time of day start up and was conducted at 11:30 A.M. - 3:30 P.M. Samples were taken at the same basic sampling locations. Samples were processed as in part one. This plant used a different sanitizing system so samples 5, 6 and 7 were not comparable between plants. During the sampling period, this plant processed eggs which were brought to the plant washed. The washing unit's brushes were used on two occasions (May 20 and 21 as shown by asterisk).

Wastewater of the egg washing machine at Plant B contained numerous pin-point colonies which were present even at the zero time of operation. Since this indicated microbial seeding in the system, we prepared additional samples for incubating thermoduric microorganisms. These organisms in wastewater did not grow at 55°C which seem to cancel out thermophiles. It is believed that pin-point colonies had become established in the wastewater tank and survived chlorination. These organisms are sometimes present in liquid egg samples.

Appendix Table 1. TOTAL BACTERIAL COUNTS ON SPC AGAR OF THE EGG PROCESSING PLANT A

	Time	Samples	4/11/74	4/12/74	4/15/74	4/16/74	4/18/74	4/19/74	4/23/74*	4/24/74	4/25/74	4/26/74
Water-wash (Raw eggs 6/300 ml of H_2O)	8	1	4,100,000	9,500,000	2,710,000	3,100,000	1,900,000	830,000	4,200,000	1,970,000	1,950,000	3,500,000
Water-wash (Eggs mach. washed 6/300 ml H_2O)	8	2			940,000	620,000	1,780,000	800,000	249,000	440,000	203,000	450,000
	12				(3,500,000)	(2,560,000)	(2,210,000)	(2,700,000)	(1,450,000)	(910,000)	(1,100,000)	(2,100,000)
Water-wash (Eggs after chlorine 6/300 ml H_2O)	8	3_0	700,000	5,500,000	770,000	4,200,000	970	2,530	58,000	1,150	230,000	127,000
	9	3_1	210,000	1,350,000	270,000	6,300,000	180	1,730	110,000	880	96,000	56,000
	10	3_2	69,000	700,000	140,000	5,600,000	31	840	6,000	560	110,000	231,000
	11	3_3	1,460,000	1,340,000	185,000	--	30	98	21,000	910	24,000	78,000
	12	3_4	21,000	420,000	150,000	7,100,000	42	39	113,000	470	138,000	69,000
Liquid egg (as it leaves the egg breaking machine)	8	4_0	27,000	27,000	59,000	2,450,000	15	1,600	6,500	1,850	51,000	72,000
	9	4_1	43,000	84,000	190,000	3,100,000	30	550	53,000	2,150	103,000	24,000
	10	4_2	295,000	31,000	85,000	1,950,000	38	2,980	7,200	950	169,000	93,000
	11	4_3	2,200,000	190,000	115,000	--	160	300	--	770	59,000	21,000
	12	4_4	3,000,000	2,840,000	178,000	2,490,000	98	256	9,500	2,450	77,000	27,000
Rinse of egg breaking mach. after sanitizing	8	5	9	15	20	33	18	32	5	8	0	63
Rinse of egg breaking mach. after operation	12	6	1,600,000	5,300,000	940,000	850,000	1,230,000	2,300,000	1,900,000	880,000	1,230,000	1,900,000
Rinse of egg breaking mach. after sanitizing	12	7	490	130	45	39	24	65	167	123	201	173
Overflow of wastewater	8	8_0	280,000	3,600,000	235,000	3,100,000	77,600	14,000	205,000*	1,230,000	1,100,000	1,890,000
	9	8_1	300,000	9,000,000	143,000	5,400,000	23,400	9,000	285,000	790,000	90,000	1,780,000
	10	8_2 *	2,000,000	4,100,000	310,000	4,100,000	19,100	11,500	470,000	810,000	800,000	560,000
	11	8_3	7,000,000	2,750,000	245,000	--	7,900	10,800	580,000	1,050,000	154,000	4,500,000
	12	8_4	28,000,000	10,000,000	400,000	5,900,000	16,200	16,900	970,000	940,000	227,000	3,900,000
Wastewater from egg washing machine	12	9	340,000,000	430,000,000	290,000,000	390,000,000	245,000,000	460,000,000	259,000,000	410,000,000	210,000,000	350,000,000

*Brushes were used

Appendix Table 1. TOTAL BACTERIAL COUNTS ON SPC AGAR OF THE EGG PROCESSING PLANT A

	Time	Samples	4/11/74	4/12/74	4/15/74	4/16/74	4/18/74	4/19/74	4/23/74*	4/24/74	4/25/74	4/26/74
Water-wash (Raw eggs 6/300 ml of H_2O)	8	1	4,100,000	9,500,000	2,710,000	3,100,000	1,900,000	830,000	4,200,000	1,970,000	1,950,000	3,500,000
Water-wash (Eggs mach. washed 6/300 ml H_2O)	8	2			940,000	620,000	1,780,000	800,000	249,000	440,000	203,000	450,000
	12				(3,500,000)	(2,560,000)	(2,210,000)	(2,700,000)	(1,450,000)	(910,000)	(1,100,000)	(2,100,000)
Water-wash (Eggs after chlorine 6/300 ml H_2O)	8	3_0	700,000	5,500,000	770,000	4,200,000	970	2,530	58,000	1,150	230,000	127,000
	9	3_1	210,000	1,350,000	270,000	6,300,000	180	1,730	110,000	880	96,000	56,000
	10	3_2	69,000	700,000	140,000	5,600,000	21	840	6,000	560	110,000	231,000
	11	3_3	1,460,000	1,340,000	145,000	--	30	98	21,000	910	24,000	78,000
	12	3_4	21,000	420,000	150,000	7,100,000	42	39	113,000	470	138,000	69,000
Liquid egg (as it leaves the egg breaking machine)	8	4_0	27,000	27,000	59,000	2,450,000	15	1,600	6,900	1,850	51,000	72,000
	9	4_1	43,000	84,000	190,000	3,100,000	30	550	53,000	2,150	[illegible]	24,000
	10	4_2	295,000	31,000	85,000	1,950,000	38	2,980	7,200	950	189,000	93,000
	11	4_3	2,100,000	190,000	115,000	--	180	300	--	770	59,000	21,000
	12	4_4	3,000,000	2,840,000	176,000	2,490,000	98	256	9,900	2,450	77,000	27,000
Rinse of egg breaking mach. after sanitizing	8	5	9	15	20	33	18	32	5	8	0	63
Rinse of egg breaking mach. after operation	12	6	1,600,000	5,300,000	940,000	850,000	1,230,000	2,300,000	1,900,000	880,000	1,230,000	1,900,000
Rinse of egg breaking mach. after sanitizing	12	7	490	130	45	39	24	65	167	123	201	173
Overflow of wastewater	8	8_0	280,000	3,600,000	235,000	3,100,000	77,600	14,000	205,000*	1,230,000	1,100,000	1,890,000
	9	8_1	300,000	9,000,000	143,000	5,400,000	23,400	9,000	285,000	790,000	790,000	1,780,000
	10	8_2 *	2,000,000	4,100,000	310,000	4,100,000	19,100	11,500	470,000	810,000	800,000	560,000
	11	8_3	7,000,000	2,750,000	245,000	--	7,900	10,800	580,000	1,050,000	154,000	4,500,000
	12	8_4	26,000,000	10,000,000	400,000	5,900,000	16,200	16,900	970,000	940,000	227,000	3,900,000
Wastewater from egg washing machine	12	9	340,000,000	430,000,000	290,000,000	190,000,000	245,000,000	460,000,000	259,000,000	410,000,000	210,000,000	350,000,000

*Brushes were used

Appendix Table 2. TOTAL BACTERIAL COUNTS ON SPC AGAR OF THE EGG PROCESSING PLANT B

	Time	Samples	4/30/74	5/1/74	5/2/74	5/7/74	5/8/74	5/9/74	5/20/74	5/21/74	5/22/74	5/23/74
Water wash (Raw eggs 6/300 ml)	3:15	1	28,000	283,000	140,000	290,000	135,000	60,000	1,300,000*	3,600,000*	65,000	91,000
Water wash (Eggs mach. washed 6/300 ml)	3:15	2	90,000	178,000	76,000	190,000	69,000	last sample 2:30	40,000	250,000	120,000	13,000
Water wash (Eggs after chlorine 6/300 ml)	11:30	3_0	81,000	4,200	183,000	4,400	181,000	19,000	no samples	29,000	38,000	140,000
	12:30	3_1	154,000	158,000	45,000	165,000	40,000	24,000		110,000	74,000	110,000
	1:30	3_2	450,000	98,000	205,000	94,000	210,000	21,000		42,000	55,000	90,000
	2:30	3_3	68,000	166,000	9,200	173,000	90,000	33,000		170,000	19,000	120,000
	3:30	3_4	770,000	88,000	150,000	90,000	41,000	last sample 2:30	4,500	80,000	21,000*	83,000
Liquid egg	11:30	4_0	50,000	18,000	8,400	18,300	7,900	1,490	no samples	21,000	1,950	5,000
	12:30	4_1	63,000	150,000	160,000	147,000	164,000	860		19,000	4,000	3,000
	1:30	4_2	7,400	5,900	5,500	5,900	5,200	17,200		53,000	2,150	38,000
	2:30	4_3	83,000	115,000	20,500	111,000	21,000	2,900		11,000	37,000	9,700
	3:30	4_4	21,500	51,000	17,500	48,000	17,000	1,760	140,000	242,000	120,000	4,200
Rinse of egg breaking mach. after sanitizing	11:30	5	0	0	10	130	19	87		1,500	1,760	900
Rinse of egg breaking mach. after operation	3:30	6	9,000,000	11,900	77,000	60,000	210,000	165,000	850,000	1,300,000	90,000	145,000
Not taken		7										
Wastewater from egg washing machine	11:30	8_0	15,300,000	250,000,000	1,390,000,000	245,000,000	430,000,000	2,040,000	no samples	11,500,000	62,000,000	didn't use washing machine
	12:30	8_1	261,000,000	165,000,000	2,100,000,000	190,000,000	290,000,000	1,850,000		19,500,000	74,000,000	
	1:30	8_2	135,000,000	200,000,000	2,400,000,000	210,000,000	2800,000,000	1,790,000		24,000,000	65,000,000	
	2:30	8_3	4,800,000	116,000,000	[illegible],600,000,000	170,000,000	2700,000,000	23,000,000		25,000,000	69,000,000	
	3:30	8_4	28,400,000	2800,000,000	[illegible],000,000,000	2,400,000,000	3000,000,000	26,400,000	58,000,000	23,000,000	71,000,000	1,550,000

*Brushes were used

Although most of the eggs processed at this location were clean and graded eggs, the wastewater had far greater numbers than the plant in Appendix Table 1, which had not used detergent, but plain hot water action alone removed microorganisms. Further investigation seems warranted from these brief data. In Appendix Table 1, samples 3_0 through 3_4 are particularly interesting. The data show egg surface counts following washing and a chlorine spray. The chlorinator was faulty during the five days of 4/11/74 through 4/16/74. These counts suggest that chlorination rather then washing appears to be the more valuable treatment.

APPENDIX C

RECOVERY OF EGG WASTES FROM THE EGG WASHER

An egg-breaking system has many integral operations. One unit operation in the system is egg washing. The egg washing function generates about 8.5% of the total liquid waste outflow of an egg-breaking system. This does not seem to be a major contribution to the total waste unit it is considered that it can contain as high as 30% - 50% of the total BOD_5 generated by the total plant operation. This BOD_5 is caused by eggs broken and lost during the washing process.

Broken whole eggs represent almost all of the 1.5% total solids of the egg washer waste. Reclamation of this waste would be of major importance to an egg-breaking plant in two ways: 1) the BOD_5 effluent of the plant would be substantially reduced, 2) reclaimed waste would provide a high protein material for use in animal feeds.

METHODS

During this study three methods for reclaiming the waste were tried, each using concentrated waste. One method involved forming a slurry with ground corn or acid whey powder while the other two were drying of the concentrate with hot oil or a drum drier. The concentrate waste was prepared by open kettle evaporation of the egg washer waste with steam at 4 psig. Concentrates of 8:1 or 11:1 were produced with 11.6 % and 16.2% total solids respectively.

The slurry method of recovery used the 8:1 concentrate as a base. The slurry was formed by adding a weight of ground corn or acid whey powder equal to the solids of the concentrate and heating to a boil for 5 minutes.

Materials dried in the hot oil were the 8:1 concentrate, the ground corn-egg waste slurry, and the acid whey-egg waste slurry. Drying was accomplished by injecting the material into oil at 204°C heated in a deep fryer. The dried material was collected by screening of the oil using muslin cloth.

Drum drying was accomplished using the 11:1 concentrate. A double drum drier was fed the concentrate as it rotated at a speed setting of 3.5. Steam was supplied at 60 psig. via a regulator valve. The dried material was removed from the drum with "doctor" blades and collected.

RESULTS

The concentrates were made with relatively little trouble. Some problem with foaming was encountered initially but as the concentration increased the foaming dissipated. Some coagulation occurred in the 11:1 concentrate, but this occurrence presented no problem for its use on the drum drier.

The slurry with ground corn had viscosity about 10,000 centiposes with a wholesome-like yellow color. The acid whey-egg waste combination did not form a slurry but was a heavy liquid. The ground corn-egg waste slurry would lend itself well to drum drying although this was not done.

Drying by hot oil was troublesome and presented a problem of getting rapid separation of the dried material in the bench-top apparatus. The 8:1 concentrate formed very small particles which tended to scorch before separation from the oil. The acid whey egg waste mixture behaved very similar to the plain whey concentrate. The ground corn-egg waste slurry dried very well in the oil giving large particles which were readily separated from the oil. All of the materials tended to retain an excess of oil which could not be prevented with the equipment used.

No problems were encountered with drum drying once the rate of feed was properly adjusted. The concentrate coated the drums evenly and when dried was removed easily by the "doctor" blades. The final product had a light gray-brown color and a texture similar to that of dried pablum.

DISCUSSIONS

The slurry method with ground corn, because of the simple technology involved, lends itself to the small plant. The slurry could be marketed to local farmers for animal feed thereby minimizing the added cost of transporting a material such as this any great distance. For the larger plant, with greater production capacity, the slurry should be taken to a dry form for marketing over a greater area.

Use of hot oil for reclamation of the egg washer waste does not appear to be applicable to the small plant. A large capital investment would be necessary to acquire the specialized equipment for processing. A large volume of product for processing would be necessary to justify this expenditure. Although this investigation tended to show it is feasible to dry the egg waste in the hot oil, further investigation using the refined commercial process is necessary before final conclusions could be drawn.

The drum drier is able to produce a very desirable product from the egg washer waste. Again, because of capital investment, this operation is suited to the larger plants with greater volume and possibly drying equipment already present.

Appendix Tables 3 and 4 show selected nutritional characteristics of the products previously described.

Appendix Table 3. COMPOSITION OF DRY EGG-WASHER WASTE

Constituent	gms/100 gms
Water	4.0
Protein	58.33
Fat	23.65
Carbohydrates	5.07
Ash	9.03

Appendix Table 4. PROXIMATE COMPOSITION[a] OF GROUND CORN-EGG WASTE MIXTURE

Constitutents	Ground Corn-Egg Waste Slurry gms/100 gms	Ground Corn-Egg Waste, Dried, gms/100 gms
Water	77.0	4.0
Protein	8.18	34.14
Fat	3.34	13.95
Carbohydrate	9.83	42.73
Ash	1.18	5.16

[a] Based on calculation using U.S.D.A. Agric. Handbook No. 8 values for ground corn.

NEW PRODUCT DEVELOPMENT USING EGG WHITES

When the egg breaker separated whole eggs into whites and yolks it was noted that whites were not handled as carefully as yolk solids and this appeared to generate the major portion of losses for the run. Because egg whites are mostly colorless they are not easily observed when lost to the floors. Egg whites are valuable for use in puddings, milk shakes, ice cream. The industry should look again for opportunities to use egg whites in products which traditionally were strongholds for non-fat dry milk or whey powders.

An illustration of one food reformulation to increase the use of liquid egg white is shown with rice pudding. Whole eggs, normally used in rice pudding, were deleted and two formulations using egg whites at 34.2% and 46.7% by weight were prepared. Both formulations rated well by our food panel tasters. The 34.2% formulation had a more preferred textural quality than the higher formulation. Liquid egg whites' impact on the nutritional quality of the rice pudding indicates that the lower calories, lower fat, and higher protein levels ought to make the reformulated products very appealing.